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ABSTRACT

The LOGO activities of a group of 16 sixth-grade students, representing a full spectrum of ability, are documented with a view of developing ways of capturing the learning possibilities of such an environment. The first group of eight subjects completed 25 closely observed hours, extending over seven weeks, in a LOGO classroom situated in a Brookline School. This is an interim report on these observations designed to exhibit the content of what has been learned, and insights into both the variety of cognitive styles of the pupils and the variety of learning situations available to a teacher with which to respond to different pupil styles and analysis. The current state of analysis is presented without any effort to prune the considerable redundancy which has been generated in the process of doing this multiple-cut exercise. (Author)

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Massachusetts Institute of Technology
Artificial Intelligence Laboratory

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A.I. Memo No. 484

LOGO Memo No. 49

INTERIM REPORT OF THE LOGO PROJECT IN THE BROOKLINE PUBLIC SCHOOLS:

An Assessment and Documentation of a Children's Computer Laboratory

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SE 035 489

Abstract

The LOGO activities of a group of 16 sixth-grade students, representing a full spectrum of ability, are being documented with a view to developing ways of capturing the learning possibilities of such an environment. The first group of eight subjects have completed 25 closely observed hours, extending over 7 weeks, in a LOGO clasroom situated in a Brookline school. This is an interim report on these observations designed to exhibit the content of what has been learned; and insights into both the variety of cognitive styles of the pupils and the variety of learning situations available to a teacher with which to respond to different pupil styles and abilities. We have a large amount of data available for analysis, and we are interested in looking at this material from several points of view. The current state of our various analyses is presented here, without any effort to prune the considerable redundancy which has been generated in the process of doing this multiple-cut exercise.

This work as been carried out jointly by members of the MIT LOGO group (H. Abelson, J. Bamberger, A. diSessa, E. Hildreth, S. Papert, D. Watt and S. Weir); and evaluation consultants to Education Development Center (G. Hein, and P. Dunning, of the Program Evaluation and Research Group of Lesley College, Cambridge). This report of the Brookline School Project summarizes our main findings and gives illustrative examples from the children's work. A detailed profile of the observations made about the child's work during the experimental period October -- December 1977 is found in Appendix I.

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I. Introduction

1.1 Aims of Study

During the period 1972-1976 the MIT Artificial Intelligence Laboratory developed a computer based learning environment whose components include:

- --the computer language LOGO
- --subject matters suitable for beginning students to move easily into programming
- --a set of instructional methods
- --a small pool of trained teachers

In 1977 we received a grant from the NSF to proceed to develop an evaluation plan of this total environment in the context of a typical urban elementary school. This document is an interim report based on a very careful study during the period October-December 1977 of 8 students covering a range of abilities. More data on these and the other 8 students in the experiment will be available in approximately six months.

Although there have been a fair number of projects in which elementary school students have been given the opportunity to learn to program computers there is very little published documentation of what transpired in such experiments. We have made a special effort with regard to the detail with which we report on the teaching, the data collection and the performance of the students.

A major benefit of this type of detailed documentation is the contribution it can make to an evaluation of the learning process in relevant domains. Finding good ways of making such an evaluation is clearly a complex task and we have explored several ways of pinpointing the skills, knowledge and attitudes which children may acquire during their LOGO work and of devising ways of demonstrating such acquisition and its transfer to other more general cognitive skills. We have used classroom observers and an interview schedule containing several measures of skill. These latter have been selected for their judged relevance rather than on the basis of previous standarization and we are clearly at the exploratory stage in this matter.

Further, we hope to provide evidence that there are advantages peculiar to a computer-based learning environment in general, and to a LOGO environment in particular as a source of pedagogical insights into the learning-teaching process.

1.2 Questions We Are Trying To Answer

In our proposal we list questions which our project is designed to answer. Here we repeat these questions, and give the answers as we have been able to formulate them so far.

1. How much can 6th grade children, in a regular school setting,.learn about computer programming, using a LOGO environment?

2. What concomitant skills that are part of the standard school curriculum (mathematics, science, and language) do children learn in the course of their LOGO work? Do they acquire concepts that would normally be considered "advanced for their age level?

3. What non-standard skills (problem-solving through planning and debugging; use of procedural thinking and computer metaphors, etc.) do children acquire in the course of the LOGO work?

4. Does the LOGO experience produce anychanges in the child's attitude towards learning or toward himself/herself as a learner, both in general, and in relation to particular subjects (e.g. mathematics)?

5. What changes, if any, can be found in the child's attitude towards using computers and towards the role of computers as part of our technological society?

In addition, in the light of the experience reported in this document, we would like to add:

6. Could we gather educationally useful data about the students by observing them in their work?

7. How can we capture what it is that a "good" teacher does so that this can be made available to other teachers.

8. Would observers with experience in different styles of teaching/learning methods identify this one as a particularly exemplary one?

9. Can we gather evidence of other unexpected outcomes, both positive and negative?

The answers to these questions, as we have been able to formulate them thus far, are:

1. Of the eight subjects, 7 were writing well formed, personally conceived computer programs by the end of the study. The eighth subject did not write programs but seems to have had a significant learning experience. Summaries of all subjects' work are in section 3.

2. Our assessment of the subjects mathematical gains is discussed in section 4.2. Delays in the NSF decision process forced us to curtail this round of the experiment eliminating work specifically on science and language. The second round of the experiment will include a brief introduction to some of this material.

3. The most salient result of the experiment is the extent to which LOGO allows the exercise of individual styles of problem-solving etc. The data bearing on this is rich and complex. A first pass at analysis is contained in section 4.3, Cognitive Styles.

4. In some cases marked changes were noted not only by us but by the evaluaters and the teachers. As one might expect the biggest changes are shown by the poor academic performers. See especially section 4.4, Affective Aspects, and the profiles of each child's work in Appendix I.

5. We did not succeed in this round in obtaining more than superficial insights.

6-9. We shall show throughout this document how much we were able to learn by doing this project about the learning process in general and about individual children.

1.3 The Subjects and Timetable

The subjects for the trial classes were chosen on the basis of consultations among the project staff and the regular classroom teachers. The teachers were asked to rate the 50 sixth-grade students on a 3-point scale of overall ability in school work: "average", "below average", and "above average" ability.

The students were then divided into groups of four, so as to achieve the following:

--a range of abilities within each group
--a balance of boys and girls in each group.
--a minimizing of scheduling problems in relation to other classroom activities.
--a compatibility among individuals in the group to ensure that the groups could be as supportive as possible for each child.

Two of these 4-unit groups from each of the two school classes form the 16 subjects of the experiment. An additional commitment to the school was that no child in the 6th grade was to be excluded from the LOGO experience and this was achieved using M.I.T. student volunteers. These latter children do not form part of the experiment and their activities are not recorded here.

This report concerns the first 8 of our 16 experimental subjects. These 8 subjects were divided into 2 classes and received the following exposure to the LOGO environment.

Teaching periods over 7 weeks -- 11/4/77 -- 12/21/77

Class I		Class II	
5 x 90	7 hrs. 30	7 x 90 min	10 hrs. 30 min
13 x 60	13 hrs	6 x 80 min	8 hrs.
7 x 40	4 hrs. 40 min	10 x 40 min	6 hrs. 40 min
25:	25 hrs. 10 min	25:	25 hrs. 10 min

Teacher Ratings of Students

	Whole Sixth Grade n=50	Experimental Group n=16
I Above average	19	6
II Average	15	4
III Below Average	16	6

ACHIEVEMENT TEST SCORES: NATIONAL PERCENTILE RATINGS FOR SAMPLE OF 15 SUBJECTS. **

NAME	Grade in which test was given	Total Reading Score	Total Score	Total Math Score	Overall Total
Harriet	4	99	99	96	99
Gary *	4	99	95	99	99
Dennis	4	99	75	95	94
Jimmy	4	61	52	77	61
Kathy *	4	61	66	29	54
Monica *	4	50	51	49	47
Albert	4	61	47	35	44
Darlene	4	58	52	31	43
Laura *	4	54	35	31	38
Kevin *	3	41	21	38	31
Karl	2	26	33	32	26
Betsy	4	30	12	21	21
Deborah *	3	40	8	26	20
Ray *	4	2	13	20	9
Tina	4	5	6	3	2

* in sample of 8 subjects reported in this document

** no score available for one child newly arrived at school.

2. Methodology

2.1 Research Methodology

2.1.1 Choice of Methods

We rely primarily on qualitative methdology: on observations, interviews and documentation, organized in a carefully designed framework, which provides both a conceptual structure for the project and a data management system. Our approach is similar to other research or evaluation efforts which are undertaken in direct collaboration with educational practitioners, and which are intended to have immediate impact on school situations. They are illustrative of one trend in education research, an effort to work in natural settings and to use field experiences as a basis for improving education. Similarly to other social science work in the field, the preferred methods are qualitative (Filstead, 1970) and the research design is typically of the sort that is variously described as phenomenological (Wilson, 1977) or, in the recent educational literature, as "ecological" (Bronfenbrenner, 1976), "illuminative" (Parlett and Hamilton, 1976) or "interactive" (Stake, 1967) rather than the experimental and quasi-experimental designs which are derived from controlled laboratory settings (Campbell and Stanley, 1963).

Campbell himself now takes the view (1974) that qualitative approaches are particulary appropriate when the subject of study is an interconnected area, and the goals are not simply to find out if one factor has an effect on another, but in what ways a range of factors interact with one another. The researcher is working not with a single testable hypothesis but rather within a general set of hypotheses that make up a position: a theory of personality for example, or a concept of how children learn. This deliberately makes room for the observation of surprising, or unexpected phenomena. It emphasises the importance of setting (hence the "ecology" of education); the subject's participation in the evaluation or research; and a recognition of the role of the experimentor or evaluator in any results. The traditional approach to the problem of experimenter intrusion (experimenter bias) is to try to make the situation as impersonal as possible. Thus a typical testing situation places a tester and a child (often strangers to each other) in a bare room with the tester reading a script and engaging in little interaction with the child being tested. The alternative, advocated by the qualitative method, is to recognize that even such stylized controlled encounters have a biasing effect on children. Thus, standarization is considered less important than a description and recognition of the evaluator's role. The intention is not to make the situation neutral, but to find a place for the person in research, to set up certain rules of behavior, and to assure that the role of the person is known, reported and understood.

In our design, the structure of the data collection system is not separate from the objectives of the program, but is in part shaped by them. The model for this methodological approach is a "matrix" first used by Brenda Engel at the Cambridge Alternative school (Engel, 1977) and since employed by Engel and Hein (1976) in a number of evaluation and research studies. The specific objectives of the program are matched with all available data collection means in a matrix format to develop the best correlation between types of objective and types of data collection methods. For complex and difficult to specify objectives, a greater variety of means is employed to provide a reinforcing network of data which can support any conclusions from the study.

In work on LOGO (as with research on some other computer systems) we are particularly fortunate because the system itself provides ample opportunities for documentation. Thus, for every session that a participant spends doing LOGO, there results not only the final products of that work (and any observations of the work or comments by the instructor) but also a complete record of each step taken by the participant in the form of a 'dribble' file; the print out of commands used. In the current project, this data was one of several sources used to discern to what extent children benefitted from exposure to LOGO.

The total matrix utilized in the present project is illustrated on the next page. This matrix was developed over several meetings attended by the project members.

2.1.2 Similar Work in Education Research

This approach to data collection is similar to that employed by other educational researchers. In recent years, a number of educators have used the documentation/observation approach to evaluate children's progress in school and to re-assess curriculum. Two outstanding evaluation efforts in the public schools are the work of Brenda Engel (1977, a,b) at the Cambridge Alternative School and that of Ruth Ann Olson (1973, 1974) at the Marcy Open School in Minneapolis.

In each case a wide range of data was gathered: observations, interviews with teachers, children and parents, results of manipulative tasks and work samples. The process of the evaluation was as important as the results: all components of the school community were involved, and the tasks as well as the results were simple and direct, so that all members of the community could understand them.

At the Prospect School, North Bennington Vermont, a long-term confidential effort devoted to a detailed program or evaluation and research is being carried out under the direction of Patricia Carini, founder of the school. An impressive collection of materials have been gathered since 1965, including (Carini, 1973):

children's work; eg. drawings, photos, etc.
children's journals
children's notebooks or written work
teachers' weekly records
teacher's reports to parents
teachers' assessment of children's work in math, reading, activities

curriculum trees
sociograms

Not only is this data collection systematic, but it is based on a carefully thought out research design (Carini, 1972) focused on:

1. Experimental investigations of the thinking process.
2. Observations of children's spontaneous activity to provide:
    a. longitudinal definition of developmental stages
    b. longitudinal assessment of the impact of the innovative learning situation.
3. Longitudinal observations of children, and recording of observations to provide
    a. modification and qualification of developmental stages.
    b. objectification of the continuity of transformations of affective and thematic content in the reorganization of successive developmental stages.

The work at the Prospect School has been successful, not only shedding light on child development, but as a guide for decisions about children and curriculum and as a source of data for teacher training and staff development.

2.1.3 Evaluation Personnel

We have been assisted in the design and implementation of our research plan by Dr. George Hein and Ms. Stephanie (Penny) Dunning, consultants to Education Development Center. Dr. Hein and Ms. Dunning have participated in the meetings of our research staff, aided us in drawing up our data collection matrix, designed and conducted pre-and-post interviews with the children, and carried out a series of regular observations which contributed to our data.

	Observations	Interviews	Conversations	Tests/Problems	Print Out	Kids Work	Games	Staff Journal	Kids Journal	Project Documents	Records of Seminars	Meetings with Teachers	School Records	
1. LOGO Programming	X			X	X	X		X	X		X			
2. "Heuristic" ideas used in LOGO	XX				XX	X		X						
3. Potentially transferable skills, concepts, acquired in LOGO work.	XX				XX	X	X	X					X	
4. Which ARE transferred	X	X^T	X	X			X					X	X	
5. Attitude changes Self Image Number School Computers	X	X^T_C X	X	X	X		X	X	X			X	X	Towards other Students, Workshop in groups, Sharing work, Sharing ideas.
6. "Childrens' Thinking.		X^T										X		
a. Pedagogic Insights														
b. Children talkup about mental activity	X	X	X	X			X							
7. Impact on Community; parents, teacher, school administration	X	X	X									X		
8 Outside community requirements.														

2.2 Remarks on Teaching

The LOGO language and introductory LOGO activities can form the basis for several different kinds of learning, integrated in a complex way into the actual classroom activities of the children. While these types of learning can and do occur simultaneously, it is valuable to list them as separable goals, and to assign priorities, for the purpose of developing a classroom organization and teaching strategies. The major goals of teaching LOGO, as defined in our proposed research are:

1. Learning to feel comfortable with a computer, and in control of what the computer does. The child will learn that he/she can decide what the computer will do, and have the computer carry out a set of instructions. There are many ways in which children can use the computer in their own fashion.

2. Learning the elements of the LOGO computer language. This includes commands that are included in the language, how to write and name procedures and subprocedures, use recursion and/or iteration, how to define, name and use variables, as well as conditionals and stop rules, etc.

3. Learning the "subject matter" of turtle geometry. This includes concepts involving measurement and estimation of angles and distances; the relations among angles and distances, necessary to produce certain well defined shapes such as a square, triangle, polygon, star or circle; such general geometric concepts as similarity, scaling and symmetry, etc.

4. Learning to develop problem solving skills. This includes such things as procedural thinking, "playing turtle", "playing computer", the concept of a "bug" in a computer program, and strategies for debugging and planning, the usefulness of generalizations or "big ideas"; and the development of a language with which to discuss all these things.

The LOGO language and computer activities are designed so that all these things can happen simultaneously as the child works on projects which he or she has initiated.

The initial projects and the initial knowledge needed are designed to be simple enough that a child can learn them relatively easily, and begin to feel successful, and in control, right from the start. Additional aspects of the language and projects of greater sophistication are added as each child becomes comfortable with them. Directing the computer to carry out a series of steps involves planning. Gaps, misconceptions or errors in the planning lead to "bugs" which have to be eliminated. Thus the teacher can help the child begin to develop problem solving skills needed to debug the child's work. By discussing all of these things explicity, a language is built up that can be applied to other kinds of problem-solving situations.

In practical situations, with a group of children and one teacher, things do not always work out quite as "conveniently", as described above. Some children are extremely adept at using elements of turtle geometry to create designs and drawings, but have a great deal of difficulty with the syntax of the computer language. For others, the reverse is true. Some children may be comfortable with both, but have a limited tolerance for new approaches to problem-solving.

We have found, therefore, that in order to create a learning environment that supports the learning of all of the children in a group, we have made learning to be comfortable with the computer, enabling the learner to feel in control, the first priority among the four goals. We want the students to develop their working styles and sets of priorities, and expect that they will feel good about what they have done. On the other hand, they will not all cover the same subject matter in any given period of time. Some may carry out involved projects involving the use of subprocedures and superprocedures, but may not become adept at using recursion though they will be exposed to it. Others may use recursion expertly to create a number of fascinating designs, but may not become adept at using subprocedures. Our results show that the children have many different approaches, and successfully follow several different learning paths.

2.3 Organization of the LOGO Classroom

The classroom itself consists of four independent microcomputers, each with its own keyboard and display screen. One lineprinter is available for use with one of the computers when necessary. The children are supplied with notebooks, graph paper drawing paper, different kinds of pens, pencils and markers, as well as a full set of stationary supplies. A small round table, near a blackboard or bulletin board provides a setting for group lessons or discussions, and for informal conversation among the children. Bulletin boards around the room provide a means of display of children's work.

2.4 Specific Teaching Strategies in the LOGO Classroom

The initial contact centers around using the basic turtle commands FORWARD, BACK, RIGHT, LEFT and clearscreen; mastering syntax matters such as spacing, use of CARRIAGE RETURN; and reading and taking notice of error messages. The children are encouraged to define their own tasks, typically involving drawing a specific, "simple" figure such as a square, a house, a flower, or their initials; and to record the steps as they go along, so that they will be able to "teach it to the computer". The later involves an early introduction to writing PROCEDURES.

It is at this point, that the child begins to feel a sense of control. "I made that design!" Procedures can now be saved, repeated, showed off to friends, integrated into a larger design. The importance of the child's first procedure being an individual one (even if it's an idea that the teacher suggested and helped with) is very critical in determining the child's relationship with the computer as the classes progress.

From this point on, each child's work is different. Some get interested in repeating simple figures, introducing simple variations and repeating again. These children might get into using recursion and variables in a fairly short time. Others might have elaborate ideas for computer drawings. These children might get into use of superprocedures and subprocedures right away. The best of all worlds occurs when these children begin to show each other their work and swap ideas and approaches. Children are encouraged to borrow each other's procedures, even to copy them line by line at times. A lot of very useful debugging occurs when a "copied" procedure leads to an unexpected result.

As the classes continue, the teacher takes on the role of "guide"; in helping the children choose projects or in suggesting projects to children based on their interests and abilities. He/she will introduce new material when appropriate, encourage children to improve their programming styles by the use of model programs and suggestions for debugging, encourage the children to investigate certain areas more deeply, and in general, help the children consolidate their learning.

At intervals, the children meet for group lessons and to share and discuss their work. They each keep a notebook in which they make drawings, write out plans, record information, keep printed records of their procedures, and make a brief daily comment about what they have accomplished.

Throughout the classes, the teacher makes a daily study of each childs "dribble file" -- the complete printed record of the child's interaction with the computer. In addition to providing much of the data on which our research study of the children's learning is based, the dribble files are an invaluable source of information to the teacher as to what each child's working style, methods of problem-solving, strengths and weaknesses really are. This information is used in planning the individual teaching strategies that are developed for each child as the classes progress.

2.5 Comparisons with Similar Studies

In this section we comment briefly on four previous studies with a close realtionship to our own. In each case we point out the salient difference in methodology.

Work in Edinburgh

The largest study has been carried out in Edinburgh where three successive cohorts of 11 year-old boys at George Heriot's School have had an ongoing experience in a LOGO environment for the past 3 1/2 years. This enterprise is currently being written-up and there is as yet no published account of the work. However, personal communication between our lab and the Edinburgh group is close, and it is clear that an impressive amount of documentation of the LOGO work there has been accumulated. This allows for interesting and productive comparisons.

For example: the Edinburgh approach has been summarised from a talk given by O'Shea at the summer LOGO meeting in 1977.

"While much LOGO work has concentrated on one to one interaction of teacher and student in a LOGO environment, this effort was concerned with tactics and materials for a large group of kids. A primer was developed, with descriptions of concepts, sample programs, and worksheets. Students maintained scrapbooks documenting their successes, as well as accumulating computer output. The teacher strategy favored kids working with each other and exploring for their own answers, rather than asking the teacher to solve problems which developed.

O'Shea noted three stages of learning most of the students went through:

1. Programming only for the end product, verbal output or graphic design.

2. Style conscious programming -- making programs which include correct form, perhaps using a new concept which is being studied;

3. Programming to solve problems. O'Shea (SIGQUE 19..)

We have not found much evidence in our study of a progression through these three phases of learning. Instead we find examples of students whose predominant mode is (1) or (3) above with no obvious evidence of (2). We suggest that there may be an important connection between this difference and the work-from-a-manual approach which tends to characterize the Edinburgh work. In such a framework, there is a notion of a sequence of topics to be followed in which the presentation of topic 1 is accompanied by exposure to model programs and working through worksheet examples of the concept, after which topic 2 is moved to.

There are distinct advantages in the way this approach structures the classroom activities for teachers and children who are comfortable with such a structured approach, and indeed our description implies more rigidity than actual practice in Edinburgh warrants. What we see emerging is the possibility of isolating consequences of particular teaching styles within what may be thought of as rather similar learning environments.

Muzzy school experiment, (Feuerzeig, 1971)

This took place at an early stage in the evaluation of these ideas before turtle geometry had been developed. We deliberately selected "average" children as our subjects (unlike the present sample which contains children at a greater ranges of abilities). We used as outside observers four leading figures in the field of math education and whilst their comments were very helpful in contributing to the theoretical basis of our work, their participation did not yield useful information about how to look at children in this learning situation. Our present project constitutes a great advance in this respect.

Work at Xerox Palo Alto Research Center, 1974 - .

This is reported in TEACHING SMALLTALK by Adele Goldberg and Alan Kay (1977). There are important ways in which our learning environment resembles that developed and used by this group. As regards the selection of students, much of the Xerox work is done with "mentally gifted minors." The published details do not allow for the kinds of analyses-in-depth which we present here, concerning the different ways in which children use the possibilities of the system.

Work at Syracuse

Joyce Statz reports work using mechanical turtles. The positive aspects of her work are in line with what we observe here. However, the limitations in the quantity and quality of hardware made it impossible for her subjects to become as involved as ours were in individual projects. This factor, together with the evolution of instructional techniques since then accounts for the fact that our subjects seem to make more progress in similar time.

Student Summaries -- Introduction

The section that follows offers a brief assessment of the progress of each of the eight children in our trial classes. The assessments are summaries of the detailed analysis of each child's work to be found in section II of this report. The summaries include a statement of how the child is perceived as a student in the regular academic areas of the school, a description of "what the child learned" in the LOGO classes, an analysis of each child's particular strengths and problems, and the particular teaching strategies that were considered appropriate for each child. In surveying this material, one should bear in mind that the students' learning took place in a project oriented setting and no attempt was made to expose all students to the same "standard Logo curriculum." Rather, the teacher introduced new Logo material to students on an individual basis, and in a way which would be integrated in their individual projects. Consequently, we observed different students concentrating on different aspects of Logo. For example, some organized most of their learning experiences around the creation of free-form "emergent" designs, while others concentrated on elaborately planned projects. Most of the students' work related to computer graphics, but a few also undertook non-graphics projects. The eight students in the experimental group spanned a wide range of interests and cognitive styles. One of the strengths of this kind of Logo learning environment is that it can appeal to students across such a spectrum and allow for projects that can be of interest to each of them.

3. Individual Profiles

Gary

Gary's considered to be "extremely bright" by his teachers. (His overall national percentile ranking of 99 on his most recently recorded school achievement tests, makes him one of the two or three highest scoring students in his grade at Lincoln School.) His teachers report that they find it difficult to find ways to challenge him within his regular school program, while at the same time reporting "peculiar gaps" in his academic knowledge -- in the area of standard computational skills, for example.

Gary seems to have found LOGO to be a satisfactory challenge. He completed three major projects in different areas: using arcs and circles to draw a face; (session 7-8) creating a simple math quiz; (sessions 10-13) and drawing and animating a starship. (Sessions 13-16) He had confidently begun a fourth major project -- writing a computer program capable of "understanding" morse code, and transmitting it to a radio receiver -- when the series of classes ended. During the coufse of his work, Gary mastered the use of recusion and variables in a number of different contexts; he understood the use of conditionals and "branching"; he learned to write state transparent procedures, and to use superprocedures with modular subprocedures in drawing his starship. He was beginning to understand list and word processing, as well as the concepts of the "empty list" and the "empty word" in his last project.

Gary 's method of working was to plunge confidently into a problem "headfirst", with little advance planning. He would then encounter many bugs, which he usually enjoyed finding and eliminating -- sometimes asking for help when frustrated. He took particular delight in bugs which produced designs unlike what he had intended. Most of his work was carried out in a step-by-step fashion, resulting in long, complicated procedures, difficult to debug. Once, when specifically requested to, he carried out a revision of his starship design, to use a superprocedure, and modular subprocedure, rather than one long procedure. In this way he showed that he was quite capable of learning to improve his programming style.

My strategy in teaching him was to offer him simple models of a particular kind of procedure, give him the information he needed, and leave him alone to elaborate on the model, providing help only when asked... When one phase of a project was finished, I generally suggested some challenges that built on the finished work -- or occasionally requested that he alter or improve his work. In this way, Gary was able to move ahead on his own, at as fast a rate as he could absorb.

LOGO Programming Concepts

Name Gary

● Uses with Help
* Uses without teacher's help

session no:	1		3		5		7		9		11		13		15		17		19		21		23	
basic turtle commands	● *	● *				*																		
arc and circle primitives					●										*	*								
PRINT and TYPE			●		●																	*		
defining procedures	●	●	*																					
subprocedures	●	●			*		*	*																
inputs									●						●	●						●	*	*
conditionals and stop rules										●	●											*		
simple recursion				●					●	*	*													
recursion: varying inputs																						●		

Mathematical Concepts

session no:	1		3		5		7		9		11		13		15		17		19		21		23	
recognizing size of screen		●			●		●																	
estimating length	●	●			*	*	*																	
estimating angles	●	●				*	*																	
special angles: 90		●			*		*																	
180,360		●			*		*																	
30,60,120																								
45						●																		
shapes: square		●												*										
triangle																								
hexagon									●															
other POLYs	●	●																						
stars									●															
rectangles																								
spirals									●															
circles		●			●	*	●	*								*								
similarity and scaling																								
symmetry																								
right/left reversibility		●				*																		
back/forward reversibility		●				*	*							*	*									
cartesian coordinates																								
variables; size and direction									●						●	●								
variables to control procedures																	●					●		
positive and negative numbers																								
aggregation						*	*																	
radius of curvature	●	●																						
total turtle trip																								

A SAMPLE OF GARY'S WORK:

```
TO MATH
10 PRINT [WOULD YOU LIKE TO HAVE A MATH TEST?]
15 MAKE "ANS REQUEST
20 IF :ANS = [YES] PRINT [WELCOME TO THE WORLD OF MATH!] MATH1 STOP
30 IF :ANS = [NO] PRINT [O.K.  COME BACK AGAIN!] STOP
END
TO MATH1
5 MAKE "NUM1 WORD RANDOM RANDOM
6 IF FIRST :NUM1 = 0 GO 5
7 MAKE "NUM2 WORD RANDOM RANDOM
8 IF FIRST :NUM2 = 0 GO 7
10 PRINT ( SENTENCE [%%] :NUM1 )
15 PRINT [+]
20 PRINT ( SENTENCE [%%] :NUM2 )
21 PRINT [________]
25 MAKE "ANS TYPEIN
30 TEST :ANS = :NUM1 + :NUM2
40 IFTRUE PRINT [CORRECT!] MATH2 STOP
50 IFFALSE PRINT [TRY AGAIN!]
60 GO 10
END
TO MATH2
10 PRINT [WOULD YOU LIKE TO HAVE ANOTHER PROBLEM?]
20 MAKE "ANS REQUEST
30 IF :ANS = [YES] PRINT [O.K. HERE WE GO AGAIN!] MATH1 STOP
40 IF :ANS = [NO] PRINT [ALL RIGHT. SEE YOU NEXT TIME!] STOP
END
TO MATH3
5 PRINT [WELCOME TO THE WORLD OF MATH!]
10 PRINT [17 + 28=]
20 MAKE "ANS TYPEIN
30 TEST :ANS = 17 + 28
40 IFTRUE PRINT [CORRECT!] STOP
50 IFFALSE PRINT [TRY AGAIN. ]
60 GO 10
END
```

Kevin

Kevin is a student who is considered to be conscientious, but "below average" in most of his school work. (His overall national percentile ranking of 31 on his most recently recorded achievement tests corresponds with this assessment by his teachers.) Nevertheless, Kevin was consistently a very able student in working with LOGO.

Kevin began the series of classes with a confident and accurate control of the turtle, which persisted throughout his work. He did not initially have the same sureness in using the computer as a tool to simplify and organize his work. Kevin's most significant project was the design and animation of a large turtle (sessions 10-17), which he drew on the display screen using circle and arc procedures. While working on this project, he began to use the idea of subprocedures and state transparent procedures to simplify his work. During the last few classes he worked on projects involving the use of two and three variables to produce designs which used the idea of similarity as a guiding feature, such as his TUNNEL procedure (session 21).

Kevin demonstrated a clear understanding of the concept of variables and was able to add variables to his procedures to control both the size and shape of the design elements and the starting and stopping of the procedure. He had moved in his work from using the computer to control the turtle, to learning how to use variables to control the processes of the computer itself.

Kevin's major difficulty in working with the computer was an initial reluctance to plan ahead, or to think about and structure his work more than one step at a time. The teaching strategy that was used to deal with this was to supply Kevin with new ideas, at exactly the moment when they made the greatest sense to him. When they simplified his work or answered an immediate need. In this way he was able to assimilate new ideas, and incorporate them in his subsequent work.

LOGO Programming Concepts

Name Kevin

● Uses with Help
* Uses without teacher's help

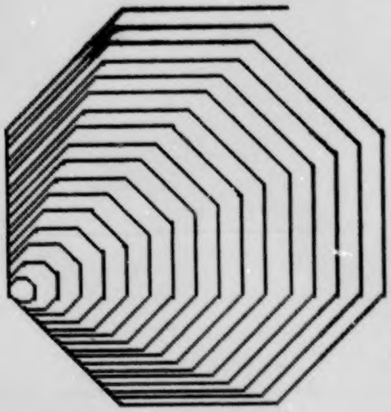
session no:	1		3		5		7		9		11		13		15		17		19		21		23	
basic turtle commands	●	●	*	*			*																	
arc and circle primitives										●	*		*											
PRINT and TYPE															●									
defining procedures		●	●	*	*	*																		
subprocedures		●	●	●	*	*																		
inputs															●				●	●	*			
conditionals and stop rules												●			●				●	●	*			
simple recursion														●					●	●	*			
recursion: varying inputs															●					●	*			

Mathematical Concepts

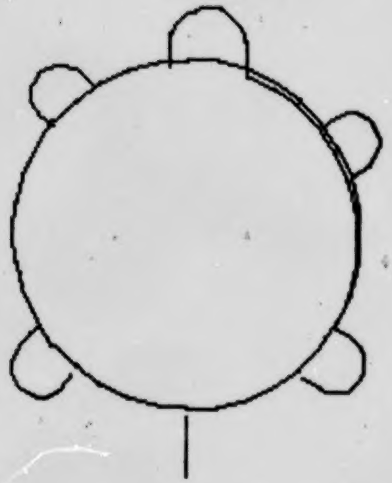
session no:	1		3		5		7		9		11		13		15		17		19		21		23	
recognizing size of screen	●		●		●		*			*	●													
estimating length	●				*	*				*	*		*	*										
estimating angles	●				*								*	*										
special angles: 90	●	●	*	*			*						*	*										
180,360			●	●	*			*			*		*	*										
30,60,120																								
45					*										*					*				
shapes: square	●	●		*		*	*																	
triangle					●	*																		
hexagon																								
other POLYs																			●	*				
stars																			●					
rectangles			●				*																	
spirals																								
circles										●	●	*		*	*									
similarity and scaling																								
symmetry																								
right/left reversibility	●	●	●				*			*			*	*										
back/forward reversibility	●									*	*		*	*										
cartesian coordinates																								
variables; size and direction																			●	●	*			
variables to control procedures															●				●	●	*			
positive and negative numbers															●									
aggregation					●		*			*	*		*	*										
radius of curvature																								
total turtle trip																								

A SAMPLE OF KEVIN'S WORK:

```
TO TUNNEL :SIZE
10 POLY :SIZE 45
20 IF :SIZE = 105 STOP
30 TUNNEL :SIZE + 5
END
```



TUNNEL 5



'TURTLE

Donald

Donald is considered to be "above average" by his teachers. He is new to the school this year (no achievement test scores available.) Donald's work in the LOGO classes revealed an overall competence in analytical approaches, combined with a certain amount of confusion about details.

Donald spent most of his class time on a single extended project: making the computer draw an elaborate HEAD, which included a beard, hair, a hat and a flower, in addition to the usual features -- eyes, ears, nose and mouth. Donald worked over a period of 14 sessions on this project (sessions 8-22). He began by drawing a picture of what he wanted the head to look like, and following the teacher's suggestion, wrote out a super-procedure to draw the head, and used separate subprocedures to add each of the features. In the course of his work, Donald had to do a great deal of estimating of both distances and angles, use arc and circle procedures, use procedures that repeat, use variables to control size and angles, and especially, learn to separate a problem into parts, to make it easier to solve. In addition, he used a POLY procedure to make a FLOWER for his head, and had to use recursion, as well as a conditional and stop rule.

Through his work, Donald had difficulty in understanding the effect of the state of the turtle at any given time. He could not always predict where the next step would occur. At times it seemed as if Donald had some difficulty in seeing exactly where the turtle was headed. The teaching strategy employed to help Donald deal with these problems was to help him develop tools of mathematical analysis, to help him figure out the best way to aim the turtle, without relying totally on visual experimentation. In this way he was exposed to the idea of using a kind of "grid" to help him maneuver the turtle around his HEAD, and to see how the total angle turned by the turtle in a given situation, was key to deciding how much more he had to turn it next. In addition, he was shown how to break up even a small problem into parts -- for example, in placing a mouth on his face, he had to decide which arc to use for the mouth, how to orient of the turtle, and to choose the correct starting point for the mouth. By separating this problem into three distinct steps he was able to overcome obstacles that might have interferred with his success. At the same time he was learning principles of geometry, computer programming, design and planning.

LOGO Programming Concepts

Name Donald

● Uses with Help.
✱ Uses without teacher's help

session no:	1	:	3		5		7		9		11		13		15		17		19		21		23	
basic turtle commands	●	●	✱			✱	✱																	
arc and circle primitives										●														
PRINT and TYPE															●									
defining procedures		●	●			✱	✱																	
subprocedures		●	●				●			✱			✱											
inputs									●						●				●					
conditionals and stop rules															●				●					
simple recursion															●				●					
recursion: varying inputs															●									

Mathematical Concepts

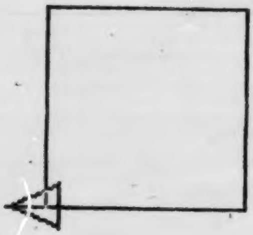
session no:	1		3		5		7		9		11		13		15		17		19		21		23	
recognizing size of screen	●		●				●	●																
estimating length	●					●		✱	✱	✱	✱		✱											
estimating angles	●					●		✱			✱		✱											
special angles: 90	●	●	✱			✱	✱	✱																
180,360		●	●																●					
30,60,120						●		●																
45											●													
shapes: square	●	●					✱		✱	✱					✱									
triangle						●	●																	
hexagon																			●					
other POLYs																			●					
stars																			●					
rectangles			●																					
spirals																								
circles									●	●														
similarity and scaling																								
symmetry																								
right/left reversibility	●	●	●					✱	✱															
back/forward reversibility	●					●							✱	✱										
cartesian coordinates																								
variables; size and direction									●						✱	✱		●						
variables to control procedures															●			●						
positive and negative numbers															●									
aggregation										●				✱										
radius of curvature							●				●													
total turtle trip																		●						

HOW TO BUILD A HEAD

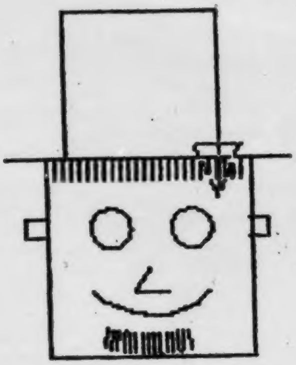
A SAMPLE OF DONALD'S WORK:

```
TO HEAD
1 BOX
2 EYES
3 NOSE
4 MOUTH
5 BEARD
6 HAIR
70 EARS
80 HAT
85 FLOWER
END
```

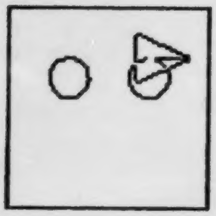
BOX



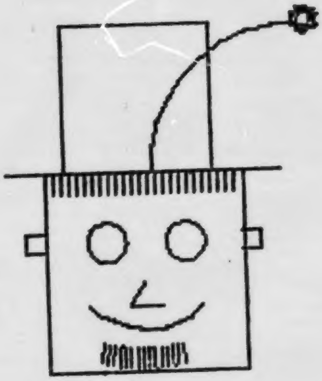
HAT



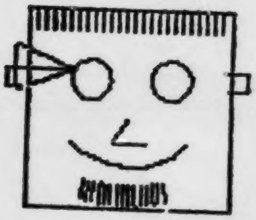
EYES



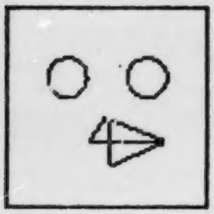
FLOWER



EARS

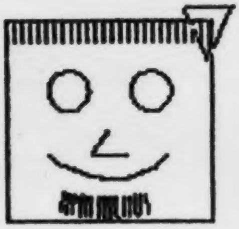


NOSE

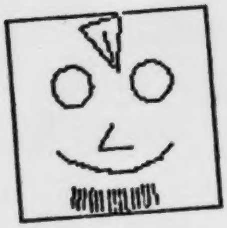


HEAD

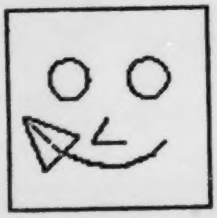
HAIR



BEARD



MOUTH



LAURA

Laura is considered to be an "average" student by her teachers. (On her most recently recorded school achievement tests, her national percentile ranking was 38.) Laura got off to a good start in her LOGO work, quickly mastering the basic turtle commands, and the use of subprocedures. By session 8 she had completed a substantial project -- drawing - foce using a top-down program structure with subprocedures for the various parts, but did not maintain a high rate of progress throughout the classes.

Laura showed great interst in making large, freely conceived designs on the display screen. She created the designs one step at a time, considering thoughtfully the size and placement of each new addition to her creation. It was difficult for Laura to make the transition to formalization of her work; to breaking it down into small tasks, and to planning and organization. Consequently, there was often a gap between what Laura wanted to accomplish, and what she was able to accomplish. Laura did carry out a few major projects: a FACE project with several subprocedures; a series of designs using circles and squares of variable sizes constructed by means of recursive procedures with changing inputs (sessions 10-15); a "madlibs" language game ((sessions 17-19), for which Laura created the basic story, wrote out lists of nouns, verbs, adjectives, and adverbs, and for which the teacher helped with most of the programming; and causing the computer to draw her initials (session 25).

Sometimes Laura appeared to be bored. In hindsight, this appears to have been a manifestation of confusion, rather than boredom. Too much stress was placed on offering her new ideas, rather than understanding her confusion, and taking steps to help her limit her choices and consolidate her earlier learning. Laura's difficulties were compounded by the fact that she did not like to ask for help, she did not like to be observed in her work, and she assumed an "air of confidence", at all times.

LOGO Programming Concepts

Name Laura

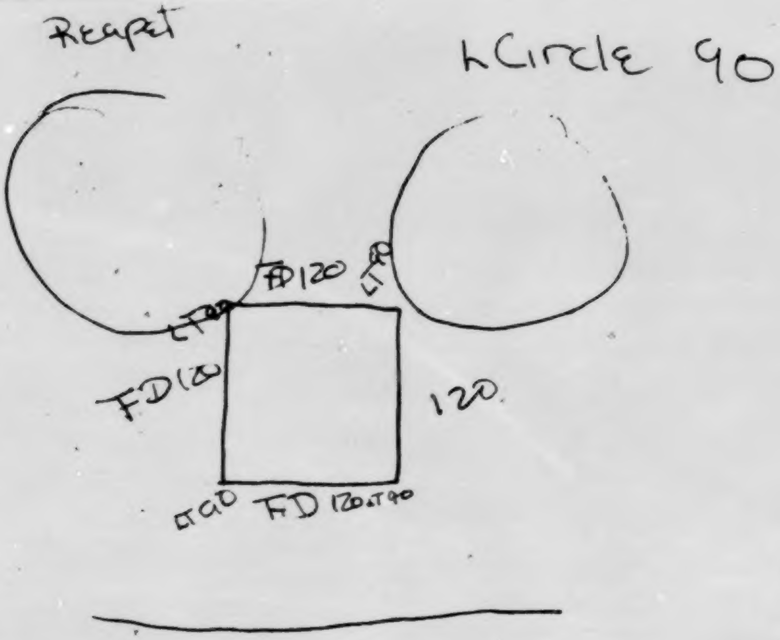
● Uses with Help
✱ Uses without teacher's help

session no:	1	:	3		5		7		9		11		13		15		17		19		21		23	
basic turtle commands	●	●				✱	✱																	
arc and circle primitives					●	✱	●		✱	✱														
PRINT and TYPE				●	●										●	●								
defining procedures	●						●	●	✱	✱														
subprocedures	●						●	●		●	●				●									
inputs												●	●	●								●		
conditionals and stop rules																	●					●	●	
simple recursion												●						●			✱			
recursion: varying inputs														●			●							

Mathematical Concepts

session no:	1		3		5		7		9		11		13		15		17		19		21		23		
recognizing size of screen	●				●	✱	●	✱	●		✱											✱			
estimating length	●	●			●		●	✱		✱	✱											✱			
estimating angles	●				●					✱												✱			
special angles: 90		●			✱	✱	✱							✱											
180,360																									
30,60,120												●	✱												
45																									
shapes: square		●						●					✱	✱											
triangle																									
hexagon																									
other POLYs	●	●																							
stars																									
rectangles	●				✱																				
spirals																									
circles					●	✱	●		✱		✱											✱			
similarity and scaling							●											●							
symmetry																									
right/left reversibility		●			✱	✱	✱				✱														
back/forward reversibility														✱									✱		✱
cartesian coordinates																									
variables; size and direction												●	●	●	●	✱		●			●				
variables to control procedures																									
positive and negative numbers																									
aggregation																									
radius of curvature	●	●																							
total turtle trip																									

A SAMPLE OF LAURA'S WORK:



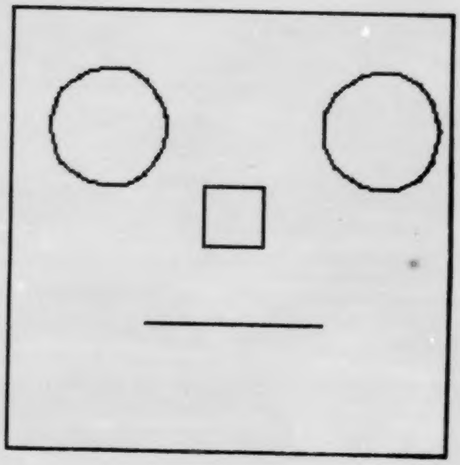
```
TO FACE
1 NOES
2 RIGHTEYE
3 LEFTEYE
4 MOUTH
5 SQUARE1
END
```

```
TO NOES
1 LEFT 90
2 FORWARD 20
3 RIGHT 90
4 SQUARE
5 RIGHT 90
6 FORWARD 20
7 LEFT 90
END
TO RIGHTEYE
1 PENUP
2 FORWARD 60
3 LEFT 90
4 FORWARD 40
5 RIGHT 90
6 PENDOWN
7 LCIRCLE 30
END
TO LEFTEYE
1 RIGHT 90
2 PENUP
3 FORWARD 80
4 RIGHT 90
5 PENDOWN
6 LCIRCLE 30
END
```

```
TO MOUTH
1 PENUP
2 FORWARD 100
3 RIGHT 90
4 PENDOWN
5 FORWARD 90
6 HIDETURTLE
END
```

```
TO SQUARE1
1
2
3
4
5
6
7
8
10 PENUP
20 FORWARD 70
30 RIGHT 90
40 FORWARD 160
50 PENDOWN
60 LINE1
70 LINE1
80 LINE1
90 LINE1
```

```
TO LINE1
1 RIGHT 90
2 FORWARD 225
END
```



FACE

Deborah

Deborah is considered by her teachers to be below average in overall ability. (Her most recent scores on a school achievement test place her in the 20th percentile nationally). She is extremely quitet and appears quite reserved in a new situation.

Deborah was very dependent on the teacher for constant reassurance, during the early stages of her work in LOGO and all through her first project -- drawing her initials (sessions 5-7). Deborah (beginning in session 8) was encouraged to experiment freely with the basic turtle commands. By limiting the numbers she chose to use as inputs to FORWARD, RIGHT and LEFT commands, she was gradually able to gain confidence and control over her work. She seemed to hve a "knack" for choosing numbers which produced interesting designs, and she gradually learned to write procedures to teach her designs to the computer. This seems to have been a breakthrough for Deborah, and she began to suggest and carry out independent projects in a purposeful way.

By the end of the series of classes Deborah had created some unusual designs which won praise from her classmates; had carrried out a major project of drawing a rabbit, which required the use of planning and subprocedures (sessions 17-24); and had developed confidence in herself and in her ability to use the computer. Deborah's parents reported that this was the first time she had been excited about anything in school. Her teachers reported that she had become more assertive in class and had asked for extra help after school, etc.

The teaching strategy that was developed in response to Deborah's extreme dependence, and her compulsive need for getting a "correct result" on her first project, was to encourage her to "experiment" with a few basic commands -- without striving for any particular result. In this way, she was able to design some simple projects, after first carrying them out by direct commands. When she chose to undertake her rabbit project, after 7 or 8 classes of free experimentation, she already understood how to write simple procedures, and how to use subprocedures as part of a larger entity. She was able to carry out the experimentation needed for each part of her project independently. The teacher's role became one of providing Deborah with help, when she needed it, in the context of work which she herself had defined, and understood.

LOGO Programming Concepts

Name Deborah

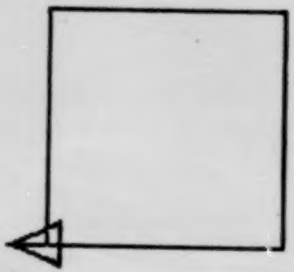
● Uses with Help
✱ Uses without teacher's help

session no:	1		3		5		7		9		11		13		15		17		19		21		23	
basic turtle commands		●	●	●		✱		✱	✱															
arc and circle primitives				●					●					✱										
PRINT and TYPE																								
defining procedures			●		●		●	●		✱				✱										
subprocedures					●													●	●			✱	✱	
inputs																								
conditionals and stop rules															●									
simple recursion															●								●	
recursion: varying inputs																								

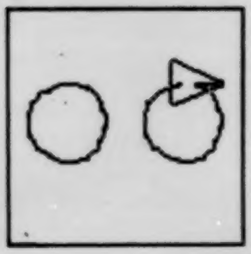
Mathematical Concepts

session no:	1		3		5		7		9		11		13		15		17		19		21		23	
recognizing size of screen								●	●															
estimating length		●		●	●		●	●	✱	✱									✱	✱	✱	✱	✱	✱
estimating angles					●	●	●	●	✱	✱							✱				✱	✱	✱	✱
special angles: 90		●	●	●	●									✱		✱		✱						
180,360																								
30,60,120										●					✱		✱							
45																								
shapes: square		●	●		●									✱		✱		✱						●
triangle																	●					●	✱	
hexagon																								
other POLYs																								
stars																	✱							
rectangles																								
spirals										●														
circles				●				●	●	✱				✱	✱									
similarity and scaling														●										
symmetry																								
right/left reversibility		●			●	●	✱	●														✱		✱
back/forward reversibility						●		●		✱						✱						✱	✱	✱
cartesian coordinates																								
variables; size and direction																								
variables to control procedures																								
positive and negative numbers																								
aggregation																								
radius of curvature																								
total turtle trip																								

A SAMPLE OF DEBORAH'S WORK:

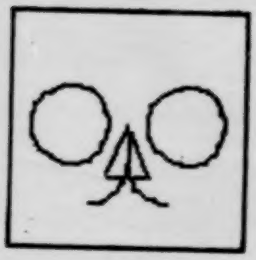


HAT



HAT

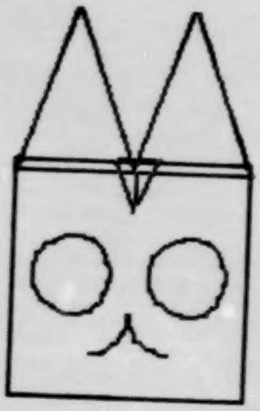
LITTLEEYES



HAT

LITTLEEYES

FACE



RABBIT

Monica

Monica is considered to be an "average" student by her teachers. (Her most recent school administed national achievement test ranking was in the 47th percentile.) Her teachers find that she prefers to base her activities solidly on things she knows, rather than to strike out into new areas.

Monica's work in the LOGO classes followed this pattern as well. She learned the basics of LOGO quickly and easily. She established a very successful technique for making interesting geometric designs by having the computer draw a shape, rotate the turtle through a fixed angle, and then repeat the sequence over and over. She learned to use recursion to produce this kind of effect easily, and eventually learned to make the angle of rotation a variable, so that the same procedure could be used to make a number of different, though related, designs. Toward the end of the series of classes, she had learned to make regular use of recursive procedures with inputs and stop rules. Throughout her work Monica had a very good sense for the state of the turtle at any moment, and could predict the location of the next shape drawn by the computer more easily than her classmates.

Monica worked very closely with Kathy during the LOGO classes and the two girls often adapted and built upon each other's projects. Monica did not work on any long term projects, or get seriously involved with editing and debugging. She often had difficulty deciding what to do, and in choosing names for her procedures. Her projects tended to be short, and if they didn't work out, she usually preferred to disregard the procedure entirely, rather than to ask for help or to try to change it. Teaching strategies for Monica focussed on helping her become more aware of the non-graphics output of the computer -- error messages for example, and of different types of bugs and how to identify and correct them. Through her own choice of working with repeated rotations, Monica was helped to understand recursion, and the use of variables, and was beginning to use conditionals and stop rules. Toward the end of the series of classes Monica expressed interst in "correcting" (debugging) a rather lengthy procedure, and was beginning to be able to look at procedures in a step-by-step manner for the purpose of analyzing and correcting them.

It is possible that Monica's would have benefitted from being able to use a carefully designed set of worksheets, structured to lead her from one concept to another, with many small projects along the way.

LOGO Programming Concepts

Name Monica

● Uses with Help
* Uses without teacher's help

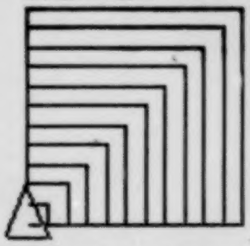
session no:	1		3		5		7		9		11		13		15		17		19		21		23	
basic turtle commands	●	●		*	*	*																		
arc and circle primitives									●		●		*						*					
PRINT and TYPE															●									
defining procedures		●	●	*		*																		
subprocedures		●	●	●	●	*		*																
inputs									●				●						●		*			
conditionals and stop rules								●				●							●					
simple recursion								●	●	●				*	*									
recursion: varying inputs															●									

Mathematical Concepts

session no:	1		3		5		7		9		11		13		15		17		19		21		23	
recognizing size of screen	●		●																					
estimating length	●				●								*											
estimating angles	●				●	*	*	*																
special angles: 90	●	●	●	*	*		*	*					*											
180,360																					●			
30,60,120						●	*		●												*			
45							●														*			
shapes: square	●	●	*	*									*											
triangle					●	●	*																	
hexagon									●	●														
other POLYs									●	●	*													
stars									●	●			*	*							*			
rectangles			●																					
spirals									●		●		*						*					
circles																								
similarity and scaling													●						●					
symmetry																								
right/left reversibility	●	●	●		●	*																		
back/forward reversibility	●																							
cartesian coordinates																								
variables; size and direction									●	●			*						●		*			
variables to control procedures									●						●				●					
positive and negative numbers															●									
aggregation					●																			
radius of curvature																								
total turtle trip																								

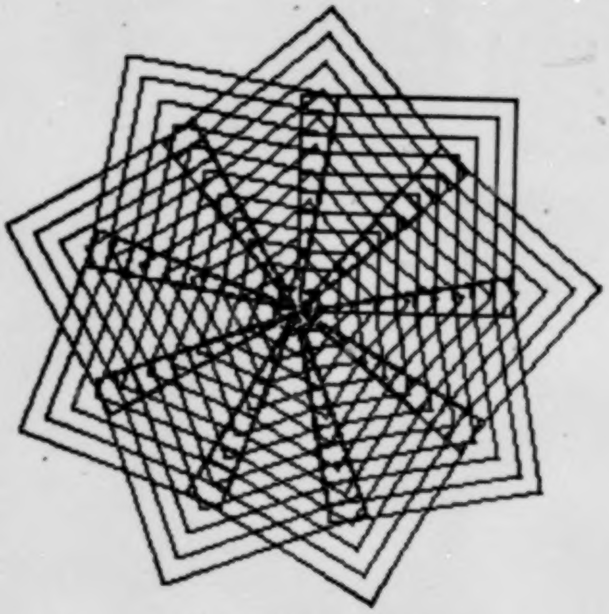
A SAMPLE OF MONICA'S WORK:

```
TO WOW
1 SQ 10
2 SQ 20
3 SQ 30
4 SQ 40
5 SQ 50
6 SQ 60
7 SQ 70
8 SQ 80
9 SQ 90
10 SQ 100
11 SQ 110
END
```

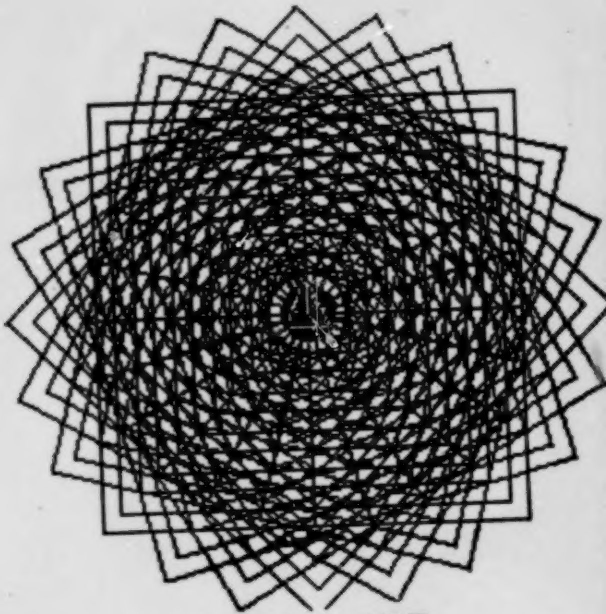


WOW

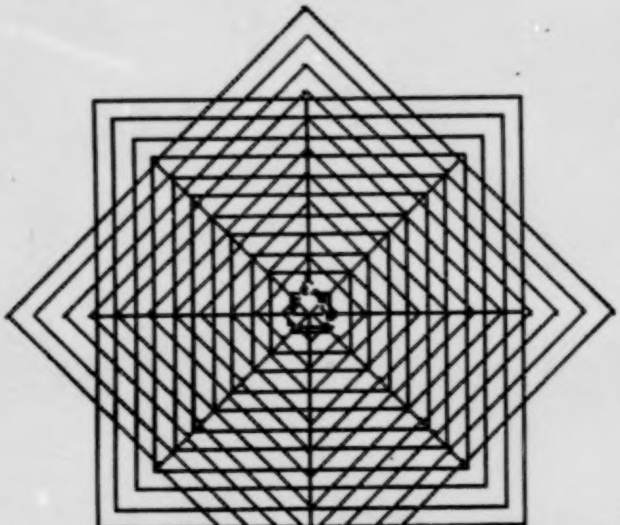
```
TO WISHWOW :ANGLE
10 WOW
20 RIGHT :ANGLE
30 IF HEADING = 0 STOP
40 WISHWOW :ANGLE
END
```



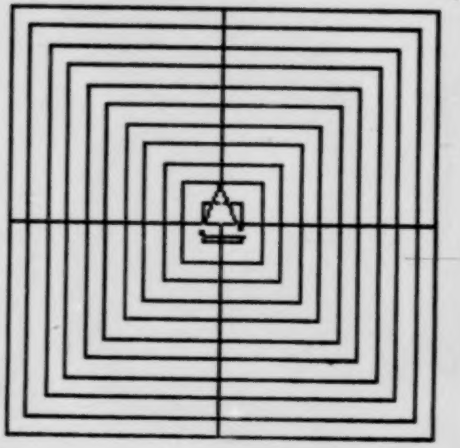
WISHWOW 160



WISHWOW 165



WISHWOW 45



WISHWOW 90

Kathy

Kathy, a student who was new to the school this year, is considered to be an "above average" student. (Her most recent school administered achievement tests place her in the 54th percentile overall.) She is cheerful, confident, and enjoys "playing" with words and ideas. Kathy and Monica worked together very closely during the LOGO classes.

61 in reading, 66 in language, 29 in mathematics.

Kathy worked mainly on small projects, gradually increasing the size and scope of her work as the classes went on. She often used the strategy of making a design, then repeating it, until it closed or until she had a design she liked. When bugs occurred, Kathy would analyze them, and work on her procedure until she felt she had corrected it. She enjoyed thinking about her work -- often making extensions or comparisons in ways that showed that she understood the importance of relations among different objects. (For example, she made a WORM procedure, then proceeded to make WORMY, twice as big, or in a different kind of relation, copied a procedure called HORSE, which drew a series of rotated boxes. When she repeated HORSE five times, she called it BARN.) Most of Kathy's work involved this kind of repeated free-form design, and the various design strategies served as vehicles for introducing such programming constructs as inputs, recursion and stop rules.

Kathy's last two projects, MONSTER and BIRDMAN (sessions 19-22), were more elaborate designs, using carefully related arcs and circles. They led Kathy into situations in which she had to use subprocedures and to engage in careful debugging.

Teaching strategies for Kathy involved suggesting projects that allowed her to extend her knowledge of ways of using LOGO, and of encouraging her to undertake projects that involved larger degrees of planning, and made it more likely that she would get involved with debugging situations. Although Kathy enjoyed creating new ideas, and she like carefully defined challenges, she did have a tendency to keep her work focussed on small challenges. She was also urged to be more analytical in understanding the effects of the variables she used.

LOGO Programming Concepts

Name Kathy

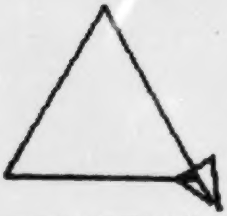
● Uses with Help:
✱ Uses without teacher's help

session no:	1		3		5		7		9		11		13		15		17		19		21		23	
basic turtle commands	●	●		●	✱	✱																		
arc and circle primitives										●	●		✱						✱					
PRINT and TYPE															●									
defining procedures			●	●	✱	✱																		
subprocedures		●	●	●	●	✱		✱																
inputs										●			●		●					●				
conditionals and stop rules												●			●					●				
simple recursion							●	●		●			✱							✱				
recursion: varying inputs													●		●					●				

Mathematical Concepts

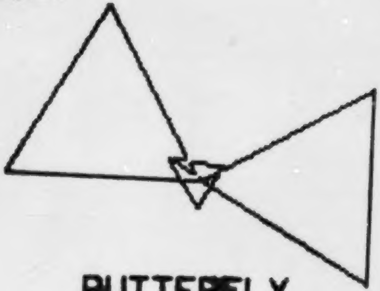
session no:	1		3		5		7		9		11		13		15		17		19		21		23	
recognizing size of screen								●																
estimating length													✱						✱					
estimating angles	●				●	●														●				
special angles: 90	●	●	✱	✱	✱								✱											
180,360	●												●								●			
30,60,120					●	●															✱			
45																								
shapes: square	●	●											✱											
triangle					●	●																		
hexagon										●														
other POLYs										●														
stars													●							●	✱			
rectangles			●	●																				
spirals																								
circles							●	●			✱		✱						✱					
similarity and scaling																								
symmetry																								
right/left reversibility	●	●			●			●											●		●			
back/forward reversibility	●																							
cartesian coordinates																								
variables; size and direction										●			●							●	✱			
variables to control procedures															●									
positive and negative numbers															●									
aggregation					●								●											
radius of curvature							●	●																
total turtle trip								●													●			

A SAMPLE OF KATHY'S WORK:



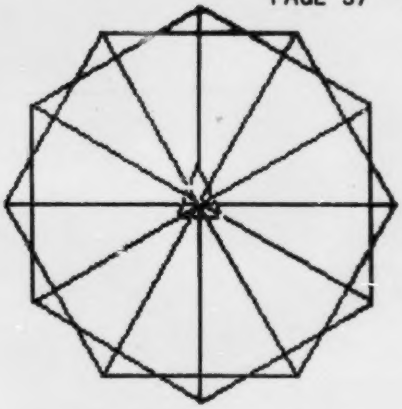
TRIANGLE

```
TO TRIANGLE
1 LEFT 90
2 FORWARD 100
3 RIGHT 120
4 FORWARD 100
5 RIGHT 120
6 FORWARD 100
END
```



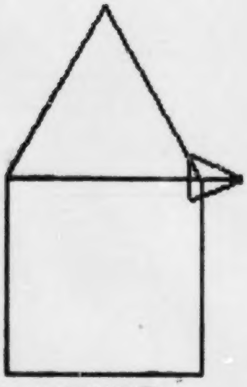
BUTTERFLY

```
TO BUTTERFLY
1 TRIANGLE
2 TRIANGLE
END
```



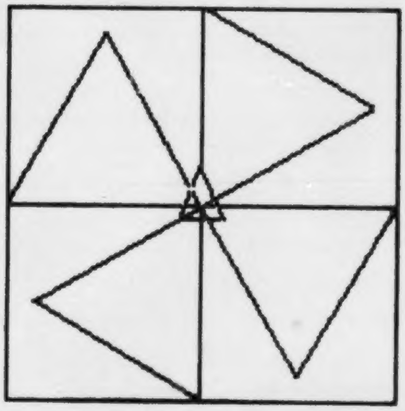
7BUTTERFLY

```
TO 7BUTTERFLY
1 BUTTERFLY
2 BUTTERFLY
3 BUTTERFLY
4 BUTTERFLY
5 BUTTERFLY
6 BUTTERFLY
END
```



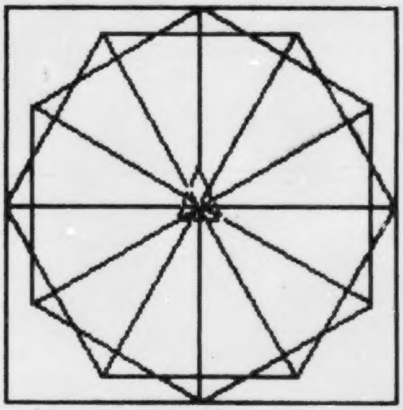
HOUSE

```
TO HOUSE
1 TRIANGLE
2 RIGHT 30
3 BOX
END
```



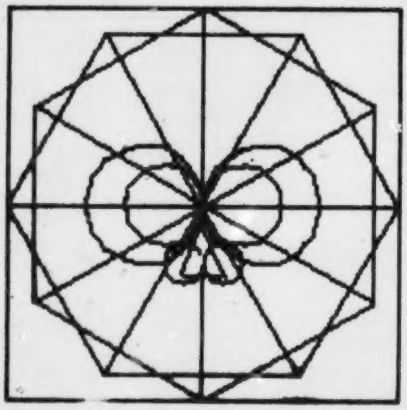
HOUSE4

```
TO HOUSE4
1 HOUSE
2 HOUSE
3 HOUSE
4 HOUSE
END
```



HB47

```
TO HB47
1 HOUSE4
2 7BUTTERFLY
END
```



SPI

```
TO SPI
1 HB47
2 RCIRCLE 30
3 LCIRCLE 30
4 RCIRCLE 20
5 LCIRCLE 20
6 BACK 30
7 RCIRCLE 10
8 LCIRCLE 10
END
```

Ray

Ray is a student who has been diagnosed by school personnel as having "learning disabilities". He is tutored individually by a learning disabilities specialist several times each week. His teachers feel that at the beginning of the year he was noticeably "slipping" in his seriousness as a student. (His most recent school administered achievement test placed him in the 9th percentile, based on his overall scores.)

Although Ray was initially quite successful in controlling the motion of the turtle, he held himself somewhat aloof from the activities in the LOGO classes. As a result, he never succeeded in writing a procedure without assistance, although he had considerable success (with help) on several projects such as drawing and animating a rocket (sessions 13-15), and in using the computer with procedures that enabled him to explore geometric shapes. In general, Ray had success using the computer in two kinds of situations; when a teacher was helping him intensely during a session, and when he was working in a way that required him to remember only one variable at a time.

The teaching strategy for Ray was to try to structure situations in which he could be successful. When these situations required a lot of help from the teacher, he would usually "forget" what to do when the teacher was no longer present. For the longest time, Ray did not engage in much "free experimentation" with the turtle. But towards the end of the series of classes (session 19) he was given a POLY procedure which requires two inputs to produce a series of closed geometric shapes, and a SPIRAL procedure which required three inputs and produced a variety of spiral shapes. Ray gradually learned how to control the inputs to produce certain shapes in a predictable way. For the first time, he began to experiment in a purposeful way, to write things down in his notebook, to use those notes to remember successful designs. He began to gain confidence in his ability to control the computer. He invited a friend to class -- together they had a very exciting time exploring the shapes produced by the POLY and SPI procedures. Ray's teachers also reported a noticeable improvement in his attitude in class, which they attributed partly tohis feeling of success in the LOGO classroom.

LOGO Programming Concepts

Name Ray

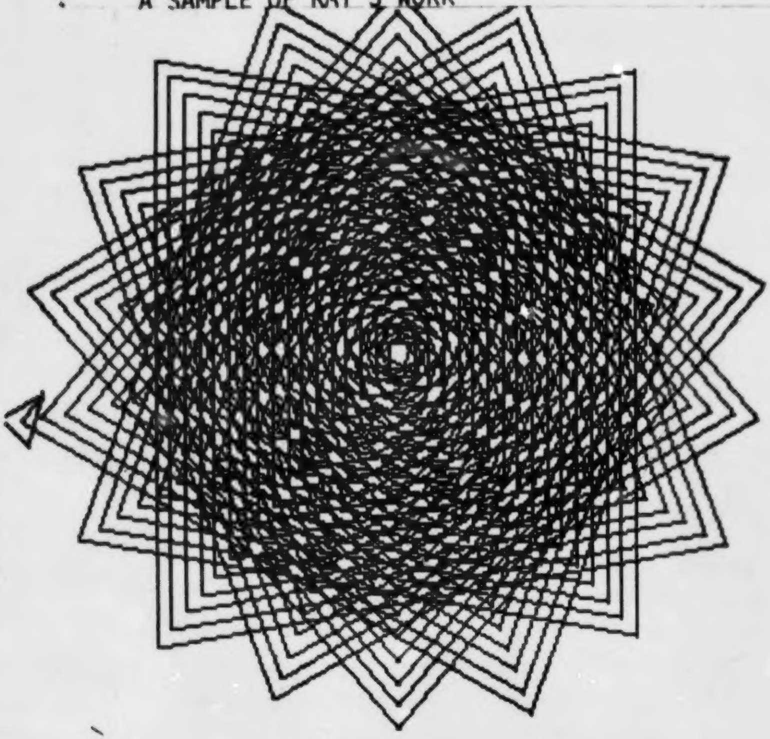
● Uses with Help
✱ Uses without teacher's help

session no:	1		3		5		7		9		11		13		15		17		19		21		23	
basic turtle commands		●	●	●				✱	✱															
arc and circle primitives								●																
PRINT and TYPE																								
defining procedures			●	●				●	●	●			●											
subprocedures									●	●			●											
inputs																		●		●				
conditionals and stop rules																		●					●	
simple recursion															●									
recursion: varying inputs																								

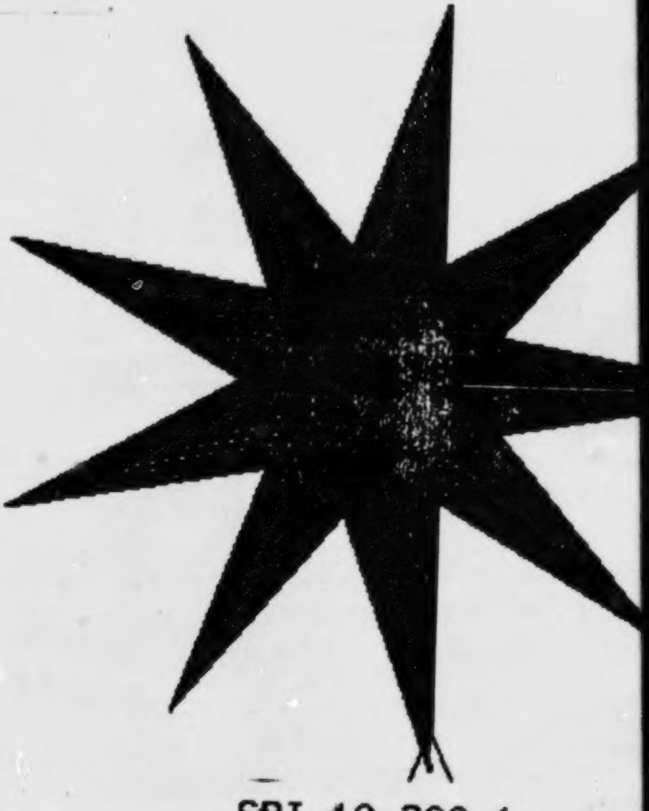
Mathematical Concepts

session no:	1		3		5		7		9		11		13		15		17		19		21		23	
recognizing size of screen				●				●	●													✱		
estimating length		●	●	✱				✱		✱		✱												
estimating angles		●	●	✱				✱		✱														
special angles: 90	●	●	●					✱				✱	✱											
180,360																					●			
30,60,120													●											
45																						●		
shapes: square	●	●	●																					
triangle										●			●											
hexagon																		●		●		●		
other POLYs																		●		●				
stars																		●		●		●		
rectangles		●	●										✱											
spirals																					●	✱		
circles																	●							
similarity and scaling														●				●						
symmetry																								
right/left reversibility		●	●	●				●					✱											
back/forward reversibility		●		●									✱											
cartesian coordinates																								
variables; size and direction															●			●		●	●	✱		✱
variables to control procedures																							●	
positive and negative numbers																								
aggregation																				●	●			
radius of curvature																								
total turtle trip																								

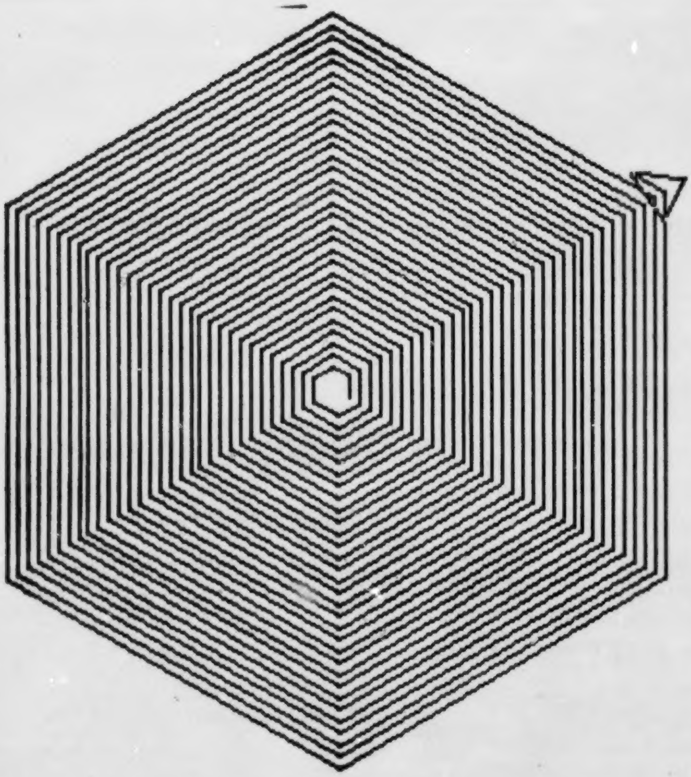
A SAMPLE OF RAY'S WORK



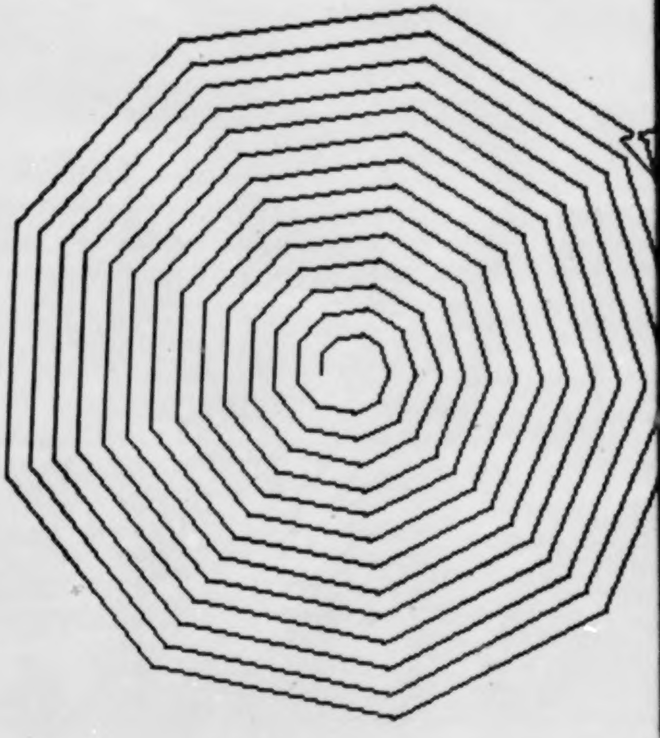
SPI 10 100 1



SPI 10 200 1



SPI 10 300 1



SPI 10 400 1

4. Theoretical Interpretations

4.1 Science Skills and Concepts Involved in LOGO

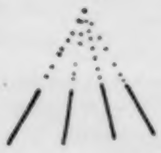
What we talk about in this section is usually called "scientific method" rather than domain-specific. The main "science concept" involved in LOGO involves the unstated analogy between the concept of hypothesis formation and testing creation of a revised hypothesis, on the one hand; and the process of writing a LOGO procedure, trying it out, and debugging it. Development of a sense of this type of process is a major goal of all elementary school science curricula, and it is a major component of LOGO as well.

To talk about "acquisition" of the kind of skills and concepts involved here would be misleading. But we can provide some evidence for an implicit or an explicit exposure to some of them in some of the children's activities.

A working scientist is accustomed to using multiple representations to achieve greater certainty and efficiency. Let us take an example, a simple physics collision problem:

> 1) A scientist abstracts the problem. Important conceptual structures (like conservation of energy) guide a translation into a formalism (perhaps an equation).
>
> 2) The formalism is manipulated in its own terms (the equation is solved).
>
> 3) The formalism is interpreted ($v = 0$ means the collision causes an object to stop).

Now consider a child drawing a picture in Logo. On the one hand there is his perception and interpretation of the picture and on the other there is the formalism of turtle drawing. The latter involves a few simple operators, some important larger-scaled structures (iteration, recursion, inputs etc.), and a collection of things it can do well and simply with these structures. The child's problem is to abstract into the formalism -- an eye becomes a circle, a nose becomes two arcs. In a more complex case the hairs in Donald's face's beard become iterated pieces of a spoke pattern.



Notice how different a conception of a series of simple line strokes is needed to make this transformation.

Now the child must execute the pieces of his reinterpreted picture within the formalism; a program must be created with the proper syntax and sequencing. All along and particularly if the program does something other than expected, the formalism must be interpreted. "What will that program do?" In the turtle environment Dan encouraged "playing turtle" as a syntonic mechanism for this interpretation.

There is another important large scale process involved in the Logo experience, the art of design. Every engineer experiences and learns to appreciate the complex interaction between ends and means, goals -- both aesthetic and pragmatic -- and materials. Logo graphics particularly invites elaborate and clear goals, and then the necessary compromise to achieve them. The reader is invited to consider, for example, Kevin's turtle detailed in section II.

This kind of learning is very large scaled, hard to pindown and measure. Though we are only at an early stage in being able to describe and objectify what is involved, that does not lessen our conviction that it is an important kind of learning. We can, however, point to some exemplary explicit encounters with various subparts and related ideas:

Heuristics - Students are given suggestions for organizing a problem for solving. "Divide a problem into parts -- do the parts separately." Certain students can be seen to have mastered this advide, Gary, Donald, Kenny. It is important that the procedure-subprocedure model reinforces in a very concrete way the idea. Donald's construction of his face was guided by the top-down structure which he wrote into his program when he started it, as much as it is by his having learned in the abstract to "subdivide."

"Divide and conquer" ties to another explicit heuristic -- plan. First approximations are useful, worry about details later. Dan explicitly said these things to the students of many occasions, and one has at least the surface evidence of the plans some students spontaneously made to support "acquisition."

Systematic Processes - One sees in Ray's "playing" with POLY an important development. In the beginning he changes both numbers rather indiscriminantly, focusing on number patterns, e.g. 123 321, rather than "meaning." Later one sees a very different pattern, changing one variable at a time, systematically. POLY 100 88, POLY 100 89, POLY 100 90 . . . He has learned some very important things about systematic enquiry. Another striking example of an appreciation for a systematic process is Deborah's entire mode of design, step by step, almost formalized procedure.

Ideas we intend to look at more carefully in the upcoming round of experiments include:

Value of explicit description
Local-Global analysis
Setting Contexts
Type-Token distinction

Debugging through cause and effect
Naming as a part of analisis and abstraction

4.2 Mathematical Behavior in the LOGO/TURTLE Classes

To decide what counts as mathematical behavior is as complex a question as the definition of mathhematics itself. As a first approach to the subject we could list specific mathematical skills or concepts which the students might have learned or exercised in the course of their work at the LOGO computer.

Before beginning the experiment we constructed a checklist of such items to look for in observing the behavior of the students. See section 3 for findings. The checklist includes some entries which were not directly observed and excludes some interesting ones which we did not think to look for. This fact itself is of some interest for the design of future experiments (including the second round of this one) and for teaching. It shows that we are inclined to recognize certain mathematical behaviors and others not.

Consider an example. When Donald was putting the hat on his face he had considerable trouble deciding how far the turtle should move along the brim of the hat before doing a left turn to draw the vertical line. Notice that there is a little problem in algebra: suppose the diameter of the brim is B and the diameter of the vertical cylinder is H. Then the turtle has to do

```
FD (B-H)/2
LT 90
FD HEIGHT
LT 90
FD H
LT 90
FD HEIGHT
LT 90
FD (B-H)/2.
```

But how do you do this if you have not yet encountered algebra and even if you have, but feel uncomfortble. Donald tried some trial and error but had trouble keeping track until he had the excellent idea of using the hairs as markers, so he could count how far he had moved the turtle. Thus the algebra was, so to speak, digitized and the problem became more tractable.

Kevin was seen to do almost exactly the same manouver in a similar problem situation: this time he used the fact that when the particular turtle used in the experiment drew a circle by repeating FD 10 RT 10 one could see a visibly brighter point at the vertex of the 36-gon which is being drawn in place of a true circle. So using internal markers should be called a mathematical behavior in the same right as estimating angles.

Another very subtle example is seen by watching carefully how Kevin moves into the intrinsic point of view when he is working on his "BIG TURTLE". By intrinsic point of view we mean a way of thinking from inside the curve..as if one could never go out of it or measure or even see anything on the outside. From a geometric point of view there is a tremendous difference and we are used to thinking of turtle geometry as an accessible, elementary school example of intinsic geometry. But of course one is not forced to use turtle concepts intrinsically..in the extreme case one can use them to set up an extrinsic cartesian (or other) coordinate system. This is something that young students often do and then make the wonderful discovery that many problems are more easily solved intrinsically. For example Kevin's turtle was made of a circle for the outline of a shell and various objects along its circumference: feet, tail, neck. An extrinsic way to do this might be to move from feature to feature in a straight line, a chord of the circle. But doing so has real problems. How long is the chord? A much better approach is to stay inside the line being drawn. This means going from feature point to feature point by moving on the circumference (this is intrinsic i.e. inside the line..which must not be confused with inside the whole disc).

Another example concerns the problem Kevin encountered in drawing extruberances like the foot. How does it pick up its place again? A truly intrinsic method is to write a second procedure called BACKFOOT whose steps are inverses of the steps of FOOT and carried out in reverse order according to the theorem of group theory.

$$(a\ b\ c)^{-1} = c^{-1}\ b^{-1}\ \ a^{-1}$$

Then FOOT BACKFOOT brings the turtle back to where it started i.e. the two procedures compounded form a state transparent procedure.

Kevin did not actually invent this idea. But he adopted it from the suggestion of the teacher in an interesting way. The suggestion made to him was not that of writing two procedures which would act as inverses for displacement but rather to make the procedure FOOT state transparent. Kevin refused the suggestion..but internalized the idea and used it in a form which is superficially rather different even if mathematically only subtly so.

It is clear from the discussion that we see in the mathematical behavior of these subjects a greater variety of "advanced" mathematical behaviors than there is any chance to experience in the ususl sixth grade class. If exercising implies developing there must be development happening. If development must show on an objective test we are still shaky in designing the tests. But the fact that we see the behavior at all contains the germ of the design of a test for it. Carrying through on this thought will be a theme of the second semester.

4.3 Cognitive Styles and Strategies

Cognitive styles is a particular abstraction of the observations of students having to do with large scaled and persistent patterns of perceiving, accumulating, and using knowledge. This category explicitly excludes social and interpersonal styles and strategies, which, while they may play an important, perhaps even dominant role in some students educational activities, are a different class of discussion.

The aims of this part of the study are several:

1. To bring to the fore some of the possibilities of LOGO as an instrument for investigating individual learning styles in a natural setting. Particularly in its artifacts of planning and programming. LOGO leaves a great many more clues to what really is going on in the child than seems typical of intellectual activities in general. These can be of great use to teacher as well as researcher.

2. To provide partial information on the learning styles of the students involved in the project, particularly in so far as it is distinct from measured school performance, "general intelligence" specific knowledge, and other measures.

3. To begin to sort out certain parameters of individual differences particularly relevant to determining the kind of Logo experience a child is likely to have. What features of Logo are particularly appropriate or inappropriate to certain students? What possible evolutions in style and strategies can we expect? What special arrangements can and should be made to accomodate individual needs?

Categories of Analysis

The analysis on cognitive styles is directed toward four categories. All the students exhibited a great number of references back to previous work and showed patterns of carryover from old to new work. These, of course, are very important in determining the intellectual development of the child and how he can be best helped to progress. The first two categories are aimed at describing these patterns.

1. Extent and Grain of Connectivity - Some students were a blurr of references backward and starts and stops of forward pointing threads. Others exhibited a much sparser pattern. Some students seemed to concentrate on large scale structures like the sort of project they would select. In contrast others had a habit of returning again and again to, for example, little techniques they had learned like a way of making pretty patterns with REPEAT.

2. Nature of Connections - Some students references were explicitly or apparently mediated by theories, conjectures and abstractions of various sorts. Others were much more literal. An example of the former is returning to an old procedure to "look inside," see again how it worked, try variations. More literal students seemed just to want to see their old procedures work again.

The two other categories concern meta-knowledge, knowing about knowing and thinking about learning.

3. Epistemology - What do the students think or appear to think knowing is about? Do they show signs of thinking about the learning process? What are the primary resources for learning; contemplation, experimentation, asking the teacher?

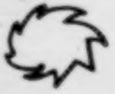
4. Assertiveness - What is their attitude toward what they know? Are they confident and agressive in their ideas, using them quickly in foreign situations. Or are they hesitant, uncertain, insistant on thoroughly exploring an idea in its original context, refusing to think, or just not thinking of that idea as applying in a new context until much later.

We elaborate these ideas by discussing two of the children in depth, and giving summaries of the cognitive styles of all the children.

1. Gary, an articulate learner

A. Theoretical - Gary manifested a penchant for theoretical and abstract thinking in a number of ways.

I. Perceiving, inventing and naming structures - Even on the first day in the midst of learning the basics, this was evident. In the course of repeating a simple 3 step procedure with Dan and Laura present, Gary observed, "Hey, its going to make a pattern!" Patterns are very important to him. The pattern developed and Gary was elated - "It made a circle!"



Laura was a bit uneasy at giving this somewhat unorthodox circle that name, but for Gary this even established a prototype for round figures. A short time later Laura suggested elaborating the design by putting "a little ball" inside the figure. Gary was off and running using the prototype structure but varying the inputs to all turtle commands, making them smaller to make a smaller circle. He quickly wrote down the procedure plan and wanted to define it without trying it out.

This episode exemplifies Gary's facility for dealing with procedural entities. He had no trouble aggregating a sequence of commands and thinking of them as "a chunk" to produce some large scale effect. As a consequence he frequently and early on made chunks into procedures and later used them as subprocedures. In one instance at the very start of a session Gary created a nice pattern αααα with two commands, seemingly by accident. Later, after a sequence of other commands, Gary defined this as a procedure without even trying it out again.

Procedural Structures caused Gary no trouble either. He essentially asked if there were a Logo command for repeating (though this in particular may be due to his experience with BASIC.) Even on the first day in invented conventions, and annotational markings for his written plans to show sequence, turtle state and other things he did or didn't know (eg. undetermined input values). Later he seemed to have invented the idea of state transparency, consistently writing state transparent procedures. He established a convention of hiding the turtle at the end of procedures, as well. This led to problems: he had to show the turtle before continuing his work. He didn't distinguish betweeen "working product" and "finished product".

2. Connections via Abstraction and Conjecture - Connections between segments of Gary's work were very often mediated by conjectures and other abstracted formulation. For example the process aggregating turtle commands e.g. RT 30 RT 30 becomes RT 60, took hold immediately and extended beyond the initial domain of experience. At one point when defining a procedure Gary aggregated two RARC 10 commands (αααα) into a RARC 20 (αααα) without trying it out first. Needless to say this kind of thing frequently resulted in bugs. Similarly, in debugging Gary frequently relied on operations performed in his head. A mistaken FORWARD command would be debugged by repositioning the turtle. Gary would then change the old command by calculating the new one in his head and wrote it into the procedure without trying it out. This contrasted markedly to most other students who would clearscreen at such a point and start again - they needed to see the correct command to believe it.

This kind of abstract mediation suggests concise summary statements of phenomena or conjecture. Gary often made these out loud. On observing the important special character of 90 angles which were discovered by another student, Gary said roughly, "A quarter of the way around... all the way around is 360, half of that is 180 and half of that is 90."

B. Assertive - As should be clear already, Gary exhibited confidence in his knowledge and conjectures. He did not hesitate to "correct" Dan when he used only a leading quotation mark, as is convention in our Logo. We have already mentioned some of the many instances of defining something without trying it out.

The circle episode on day one gave good evidence of Gary's assertive style. He voiced great confidence that his theory of producing a small circle would work. In another part of the session while counting repetitions of a basic figure in making a "circle," a typing mistake caused the insertion of an unrelated command. Rather than clearing and starting again or even pausing to think of corrective action Gary simply continued the repetition and, when counting, carefully left out the mistaken step. Thus he assumed that one error did not affect the "correct" part of the work. That kind of assumption of independence of parts is sometimes mistaken in detail, as it is here, but is often a very helpful approximation, a good heuristic which more careful and less aggressive intellects need to learn. It followed naturally from Gary's style. In many other instances Gary used this particular heuristic, assuming independence of effect of parts. In debugging he would always pursue and correct bugs one at a time.

Gary's planning and working style was assertive to the point, occasionally, of being impetuous. One would expect he would need a good way of dealing with the inevitable bugs in his plans and theories. Indeed, Gary liked bugs when he could handle them with his one at a time style. When his "smaller" circle turned out to be larger, he clapped his hands with glee... what a nice surprise! In many ways he even sought out bugs, as one can see in his playing with larger and larger inputs until something went wrong. He also spent time playing with Logo's peculiar large number arithmetic (exponential notation). Again, one can see this as a good heuristic - to search out extreme (failing) cases.

C. Diffuse, non-local style of work - Gary's is punctuated with many references back and ahead in time. One can often see in a small stretch a return to old ideas or procedures right along side of and interleaved with new ideas and pieces of future work which will eventually be put together. This kind of phenomenan is common, but in most students, reference to old work appears to be mostly consolidation. In Gary it was often used to integrate and elaborate, seeking to make connections where there were none, and pushing old ideas into new contexts. (One hardly ever saw other students printing out and examining the structure of old procedures as Gary did.) We mention a few examples:

Gary stated exploring the PRINT command on a non-graphics terminal. Without encouragement he tried to import the REPEAT command from previous work in turtle geometry.

Gary was playing with SPIN which he had just discovered. Dan wanted Gary to start using recursion and showed him a (non-spinning) example. Gary right away wrote a recursive spinning program.

Gary knew about using RT to counteract a mistaken LT. He also knew how to consolidate commands and knew LOGO could do arithmetic. These bits of knowledge might have gone unconnected in many children, but to correct a LT 99 Gary had LOGO add 99 + 99 and then used RT 198 to correct the error!

This relatively small grained, fluid and multiply connected style of work is not particularly conducive to structured programming. While Gary early on collected sequences of commands into procedures and used those in other procedures, he did not spontaneously plan out and execute independent parts of a single conception. His starship, a rather late creation, started as a long string of single turtle commands. Gary would experiment, EDIT, add, END, experiment, edit, END,... but wrote a structured program only on Dan's insistance.

Finally we return to Gary's small circle conjecture and subsequent bug. As might have been expected, he did not let the incident rest, but returned later to try exactly half inputs (rather than just 'smaller ones') to the turtle commands. This produced a same-size circle and was then immediatly used with the old circle to make a fancy design. (But he never achieved the smaller circle.)

D. Rich and Fluid Epistemology - Gary exhibited quite a bit of sophistication in knowing about knowing and learning, especially in recognizing and using his own resources. In trying to aim the turtle directly vertical, he shifted his focus from the point of the turtle to the turtle's back end, aligning it horizontally. He even articulated this 'easier' strategy.

In deciding on left or right turns while planning on paper, he sponaneously put the paper in a position so that the turtle faced directly upward, and right and left would be more easily determined.

Gary exhibited a lot of flexibility in interpreting error messages. If the message was uninterpretable, for example, 'SPIN doesn't like EMPTY as input' in response to SPIN 5000 he was not stymied. After all, 5000 is a big number and that was likely the problem, even if the message didn't say that. His next command, SPIN 2000, worked.

In a teaching role Gary operated on a typically high level. On day 2 in response to questions about how one knows how to get the turtle the correct input, he did not say, e.g., 'try 90' which he was capable of doing, but 'you have to experiment'. When Gary taught his friend J. about writing a procedure, he was explicit about his teaching goals. We quote roughly, 'I don't want to remind you to put a line number at the beginning of each line.' In response to his friend's guess of 200 to follow line 100, Gary said, 'look at the pattern!'

Special Strength's of LOGO for this style: Gary's teachers freely admitted that they had difficulty challenging him in the standard classroom. But he had no difficulty challenging himself and the limits of his own ideas in LOGO. One can easily take advantage of his ability to work things out for himself by simply giving him little models or ideas, leaving the rest to him.

In many other ways a LOGO environment is extremely well suited to this particular style even when it is not executed in such an expert way as Gary did. There are few intellectual domains available to elementary school students in which trying to put things together in a new way is as frequently successful and richly rewarded as in a computational environment.

Special Needs for this Style: A student like Gary needs little aside from being fed a few seed ideas and appropriate tools to do a lot and well in LOGO. Perhaps the greatest weakness in his style as regards LOGO is his less than natural affinity to structured planning and programming. With a little encouragement at this and in selecting and staying with a project, a lot of success is in prospect.

2. <u>Deborah</u> -- from Inarticulate Dependency to Proficient Self Confidence

A. <u>Literal</u> -- Deborah showed essentially no interest in abstract patterns or for any level of concern much above "what to do next." In drawing a six pointed star, ααααα, she never seemed to notice the repeating pattern, even in the literally repeating sequences of commands she was writing down. Even when Dan prompted her to use a subprocedure she needed much help to understand how to use it -- this in lesson 17.

Earlier Deborah drew a spiral:

```
RARC 20
RARC 20
RARC 30
RARC 30
RARC 40
RARC 40
  .
  .
  .
RARC 90
RARC 90
RARC 100
RARC 100
RARC 100
RARC 10
```

Notice the break in the pattern at the end. Certainly a pattern driven mind like Gary would have completed it intact. One suspects she really <u>meant</u> to break the pattern, feeling at that moment that the design needed something different. When she wrote a program of this, she copied each step literally from her work paper, and even checked after each <u>word</u> to see what came next.

In contrast to Gary who always had a clear expectation of what would happen, Deborah seemed always to just let things happen. When writing programs for her initials, Dan asked her to predict what would happen if she did both a D and M on the same line. She said she guessed they would draw on top of one another. The result was αααα to which she replied, "see I told you".

Hypotheticals seemed to elude her. Dan suggested one day she should number her program steps by 5. He explained carefully that if she wanted to put another step between ones it would be much easier. Though she had done a good deal of editing, her synopsis of Dan's explanation was, "Count by 5's...because its easier."

B. Non-assertive -- Deborah was always very timid about getting into things she did not feel she could dominate. Even her choice of number inputs demonstrated this. From her first day she was very conservative. In response to a slightly impatient classmate who said she should use a bigger number than 10, Deborah offered 12. She was coerced into using 20. In all of her sessions Deborah never once spontaneously used an input greater than 100! In most segments of work she selected a single angle and one or two sidelengths in terms of which she did all her explorations and drawing. When she needed longer lines Deborah used chunks; FD 60 FD 70, for example.

C. Local, step-by-step style of work

Once Deborah settled comfortably into a mode of work in LOGO her patience in a one step at a time design and programming seemed boundless. The format was so stereotyped as to seem quite formal. 1) Do some standard chunk of the appropriate action (eg. turn or move) 2) Check to see if that's right on the screen 3) write down command and continue.

The only decision seemed to be what's the appropriate action (turn or move or maybe penup). Her only global concern was if the last action fit properly into the picture. Mistakes almost always resulted in Clearscreen and start again.

We have already noted the lack of pattern perception tied up with this style. Her basic operations in the six pointed star were a forward command and a RT 60. Consistent with her mode of operation a LT 60 appeared as 5 RT 60's, and if she happened to miss a correct heading the first time around she would continue, right in step, 6 more RT 60's! Again it appears Deborah is dominated by the question "is that right? -- if not continue."

D. Deliberately restricted epistemology

Deborah seemed quite deliberately to restrict options, limit possibilities of operations, reduce her horizons so that she could dominate whatever territory she tried. One needn't look hard at her dribble file to see that it was Deborah's. A string of 30 turtle commands, Fd's Rt's BK's (no LT's) all with the same input surely marked Deborah's style.

But once she found her ground she did indeed dominate it. She meant her remark, "I know what I'm doing," in a sense which a student like Gary, for all his flair, could not.

There was a good deal of evidence outside her style of work that Deborah worked with and needed a restricted but very definite world view. What other kind of student would announce spontaneously with pride near the end of 25 session LOGO experience, "I know all about squares".

Her language for describing her own activities was also revealing. A mistake is a "goof". Experimenting is "goofing around." Actions are classified either as correct, goal directed etc. or "a goof". With such a view it's no wonder she limited her play -- one wouldn't want to "goof up".

Strengths of LOGO for this style

We firmly believe that the way to help a student like Deborah is not to force her to "expand her horizons," but to let her dominate a small world. She has no shortage of ideas or initiative, and experience will in a very natural way lead to her widening her own horizons.

The most important characteristic of LOGO for supporting a student like Deborah is that it can provide an almost empoverished domain in terms of operations and decisions in working out a plan, but a domain in which original products of endless variety can be turned out. The world of FD 30 and RT 30 is very nearly as rich as all of turtle geometry and certainly contains triangles, squares, "circles", stars, men, rabbits, abstract designs, ...perpendicular, inverse operations, the total turtle trip theorem, symmetry, estimation, ...planning, debugging, ... A secondary factor may well have been the openness of talk about bugs and debugging. Deborah could easily see that everyone, especially some of the 'brightest' students are beset by bugs which need to be worked out. There are many kinds of "goofs" to be looked at without embarassment.

Special Needs

Deborah needs help and encouragement in doing what she does best by herself. She needs to see that she knows and can do things. What follows is a list of possible particulars.

1. Writing down her plans and successes was instrumental in engaging Deborah's strengths in literal and local activities. This didn't come easily; Dan had to continually remind her until it took hold.

2. Leave her alone. One explicit part of Dan's objectives in dealing with Deborah was to make her rely on her self. Her notebook was instrumental for this.

3. Deborah had a phenomenal ability to find the right fundamental operators for what she was doing. Though she tried 20's 40's and 70's as inputs, these seemed just to fade out leaving 30's 60's and 90's. Particular circumstances mysteriously brought out just the right units. For her star Deborah used exactly one 30 degree angle to orient the first segment (without

experimentation!) then proceeded with all 60 degree angles (again without experimentation) which happens to be exactly the fundamental unit appropriate to the star. In her rabbit Deborah started with a face size of 130 (60 + 70), which caused problems symmetrically placing eyes. Her next try, without experiment, was 120, in the form of 90 and 30. We have no reason to suspect students of Deborah's intellectual style will generally have this skill (or luck) and may need help selecting fundamental operators.

3. Ray

Ray is a particularly difficult student to discuss from the viewpoint of cognitive styles because of the elaborate veneer of social and interpersonal strategies he has built up and maintains to keep people (perhaps himself included) from his intellectual world. Penetrating this veneer is the most formidable barrier to overcome in helping him to have a satisfactory scholastic experience. But again the great placticity of Logo in offering a range of experiences for the teacher to select from in individual cases pays benefits. Dan's strategy of arranging Ray's minimal committment to a very simple activity (playing with POLYs and SPIRALs) with maximal payoff (his own beautiful designs) seems to begin to penetrate the veneer, both in Logo class and outside of it.

4. Laura

Laura's epistemology seemed to emphasize knowing and minimize learning. She was anxious to demonstrate and talk about what she know (in contrast to Deborah), but had a great deal of difficulty articulating her processes of working, often seeming to indicate that they were not appropriate targets for discussion. This same attitude was evident in both her references to old work and her style of planning and executing projects. With the former she was typical of the students who would run old programs over without any attempt at analysis or at retracing the process of creation. In approaching new projects she did very little planning as if one should just know what to do. Debugging was the same; she avoided theorizing and experimenting. In contrast to Gary where the chase was the thing, for Laura the end product was the thing.

Not surprisingly her programs tended to be just strings of commands aimed at some particular concrete result, without intermediate constructs of ideas evident in either the way she wrote or talked about the program. Mediating ideas have little value.

One of Laura's real strengths was her willingness to try new things, get into new situations and make suggestions when requested. But she needed to appreciate the effort needed to attain the goals she would entertain.

Strengths of Logo: Logo teching generally involves a lot of discussion of the process of coming to know, the scaffolds of planning and debugging, analysis for accomplishing ends.

In Laura's case it is very important that she come to feel the usefulness and value of thinking about these things in themselves. Think of Logo's rich cognizance of these intermediate processes, planning, using facilitating subgoals like subprocedures, learning about techniques with broad application value (like recursion).

With Laura's willingness to push to new things, she did engage in some formidable projects. But we cannot claim that the potential helps cited above were fully realized. We would be very hopeful with more time.

Needs of this style: Emphasis on planning, on the value of understaning how to make something work, of an appreciation of the technicalities and details of program structure.

5. Kathy

Kathy exhibited a cognitive style less extreme than many of the other students. She was theoretical in many ways, like Gary, often posing for herself problems of analysis and questions to solve, rather than just "drawing a picture." She would occasionally drop an enquiry after answering her own questions without actually completing a program. She enjoyed the process of naming and describing structures, programs and activities for its own sake. She expected her ideas to work, but showed dissapointment rather easily when they didn't. In those cases she was capable of proceding with "exterminating" (as she called debugging) on her own, but did ask for help as well.

The grain of her reference to old work was not nearly as fine as Gary's; she often used procedures intact as building blocks and did not show his near compulsion to use every little thing he learned. As a consequence, she worked coherently toward her goal. When she did look back to old procedures, she occasionally modified them, again showing a concern for structure rather than just effect.

Kathy showed an awareness in many instances that she knew what she was learning and what she was having difficulty with. She avoided a troublesome area, estimating angles, and once she was told something, seldom had to be reminded about it.

Strengths of Logo: Logo allows a student like Kathy to pick and choose, as she is capable herself, what sort of project and activity she will engage in. It allows her to push her (theoretical) ideas without forcing her to go beyond her zone of comfort.

Needs: One would like to see Kathy a bit more assertive in terms of digging into things she obviously thinks of as problematical -- a little more concern for what she really would like to do and less timidity toward working on personally difficult areas (angles). It is quite likely that helping her to face up to some of these is all that she would need to succeed and get more confidence.

6. Monica

Monica, though quite similar to Kathy in many ways, exhibited a distinct style. In particular, she was much more literal than Kathy. The abstraction involved in appropriately naming a procedure (which is mostly identifying some centrally important structure and describing it succinctly) was not the pleasure for her that it was for Kathy. The connections one could see from program to program were for the most part limited to a literal simple structure -- design, turn, repeat. She did not exhibit either the urge to dig in and elaborate and change that pattern or the pulls to get into something completely new. (Contrast Kathy and even more so, Gary.) Like the even more literal Deborah, Monica took careful notes, and showed she could engage in extended and detailed work, given a good model of what she was to do.

Monica was certainly not assertive about her ideas; she seldom proposed her own and easily abandoned them when she did. Like Laura, exactly what made them work or not work was of little concern. More often she just followed others' simple models.

Strengths of Logo: Logo is quite capable of maintaining the interest of a student like Monica with simple and literal strategies for doing new things. Even design, spin, repeat is a quite rich world.

Needs: Like Deborah, Monica should probably work her way out of her own simple view of things. Luckily in Logo she can be given simple stategies which will succeed in letting her "dig in" to her own ideas (planning and debugging and systematic analysis, e.g. of POLY) as well as a few simple design heuristics (she seemed to have only one) to help her "dig out" and reach for new areas of exploration.

7. Donald

Donald's interest and ability at naming, structured planning, and analysis of problems he encountered showed him to be a theoretical worker. Though the evidence is less compelling, one seems to see a comparative lack of personal strategies for dealing with situations where analysis is awkward and experimentation is more appropriate.

In contrast to the other paradigm of theory driven students, Gary, the grain of Donald's work was not nearly as fine. In fact most of his time was spent working directly on his one project, with very few forays of into other topics, even those arising from his project, except in so far as they related instrumentally to it.

Strengths of Logo: Donald's real strength, establishing a (theoretical) frame and working within it meshed wonderfully with structured programming, allowing him to spend a huge amout of time on a single organized and eventually successful project. The freedom given him in the Logo environment to pursue such a project and elaborate and improve his large scale organizational abilities can't be usually be matched in an ordinary classroom with its fragmented tasks. Still, in this context he encountered and used a great deal of specific knowledge, Logo programming structures, and mathematics alike. For examples of the latter we mention coordinatization, geometry of arcs and angles, the total turtle trip theorem. (See the section on mathematics learning.)

Incidentally, nearly all the students (Ray the exception) displayed "attention spans" in working with their own projects if not as phenomenal as Donald's, nonetheless quite respectible. (The typical hour class session is a good reference for steady, continuous work.)

Needs of this style: Donald's strength was also occasionally a liability. In taking a triangle and making of it a house, Donald established a problem frame in the context of the initial orientation of the triangle. The tilted house had great difficulties associated with it which were eventually solved only with help in dropping that plan and replacing it in toto (rather than working out its parts). He needs to learn to occasionally subordinate plans to pragmatics.

8. Kevin

Kevin early on showed signs of a theoretical disposition, realizing special significance of certain angles, collapsing command sequences in his head (RIGHT 45 RIGHT 40 RIGHT 50 → RIGHT 45 RIGHT 90 → RIGHT 135) etc. One example more will sharply set him off from literal students: In experimenting with a procedure to draw a sequence of polygons of increasing size, Kevin discovered that he could draw a single square by setting the upper limit equal to the lower limit.

He was delighted, certainly not by a startling new effect, but by realizing and understanding an important simplification potential in a more complex structrue. (Importantly, one which satisfied a need for him, a vairable sized square.)

Context was very important for Kevin. He learned and elaborated ideas in a context and floundered somewhat when outside of one. This caused a certain large scale coherence to his work, for long periods maintaining the same context, which others, e.g. Gary, who would create a new context in which to examine the most minute detail, did not have. Unlike some (e.g. Donald) kevin did not enjoy the act of organizing a frame for his work, but capitalized on what was given to him or the necessities of th project he selected. He did not take well to structured programming.

Strengths of Logo: One of the main ideas of a Logo experience is exploring ideas in a functional context, where mathematics serves to accomplish a task which is meaningful in the student's own world view. It is clear that Kevin, more than many, needs that kind of context. Perhaps that need was met more in LOGO than in other school activities and accounted for the difference between his "below average" school work and excellent progress in Logo.

Needs: On the other hand, Kevin will need to learn the skill of organizing an intellectual frame for himself. If he can do so one would expect a great carryover to other school work.

Summary of findings

1) Logo and students' experiences - All students regardless of knowledge or style were to some extent engaged by Logo activities. Most actively and regularly contributed to setting the style of work which they did (Ray the notable exception). Some had exceptional experience in meshing their styles and strengths with Logo (Deborah, Gary, Donald) going quite clearly beyond what they had had in their other classrooms.

2) Meshing with cognitive styles - We think the Logo environment created at Brookline showed extraordinary versatility in dealing with such a diversity on its own terms. The process of selecting and merging facets of the known Logo possibilities and developing new ones so as to engage strengths and overcome weaknesses in students' individual cognitive styles is rewarding and seems to us an immensely important area for future research.

3) Logo as an instrument of study - We think Logo has two real strengths in coming to understand individual students and their learning. First, most school activities are so fragmented and out of a student's control that the students never have an opportunity for displaying the coherence and true strengths of their own style. Secondly few school situations compare to Logo in concretizing the students processes of learning and accomplishment. The artifacts of a partially completed design, a particular program structure, a pattern of play or experimentation on the display or on the teletype turned out to be vitally important parts of our observations. Perhaps only an art class could match the "manifesting of process" and then in a domain quite far from school's "academic" subjects. The annotated dribble files of all of the students' typing (in conjunction with in class observations) played an important role.

4.4 Affective Aspects

An integral part of the learning environment being discussed here is our stance towards the affective aspects of learning. We do not simply hope that our teachers will be nice, kind supportive people and that, therefore, this aspect will take care of itself. We build into the design of the environment, we think, tools for a teacher to use to achieve progress in these areas as an explicit aim of the teaching/learning encounter.

To list some aspects whose emergence is favored by our system:

-a student can feel in control; have agency.
-a student can see how learning does not have to be something apart from oneself, and uninteresting: SYNTONIC learning.
-a student can realize a personal style.
-a student can admit not knowing because he will know out to find out.
-a teacher can admit not knowing for the same reason.
-"playing around" does not mean "stealing time out" from learning.
-Getting something right is not only to be translated into a high score: what you have achieved is happening out there for you to see and feel good about and to be seen by others and admired.

In practice effects of this sort will not necessarily emerge, and whether they do or not has to do with the goals, personality and skills of the teacher involved (see question 7 in the introduction).

4.4.1 Comments and Questions Ensuing:

1. Working with a computer will be seen both as a prestigious activity and a potentially fearful activity. So we can expect contrasting effects which pull in opposite directions; and these will underlie all of our findings.

2. We have an unusually favorable teacher/pupil ratio, which must have a strong effect on our findings.

3. There are likely to be some strong and relatively unexplored components of the relationship between child and various elements in this new learning environment:

--explicit and implicit anthropomorphising of the "turtle" and its behavior

--an effect flowering from the degree of control over the mechanical device

--the effect of being in the teacher/adult role in relation to it

--identification with the turtle on the basis of its movement in space

--even more striking motivational attribution: procedures "needing" inputs; the turtle "wanting" to go up there now.

There is a powerful potential for evil as well as for good in this whole computer presence and we need to be alerted to it, and to look closely at what it can mean.

4. Motivation in this learning environment can be complex. We can think of the child as developing a rather complex goal structure which at its best will include rewards inherent in

the task; the fun and joy of making lovely and interesting pictures and of solving non-trival problems; the admiration of peers and "significant" adults.

Examples:

(i) Ray: "this thing is going to get me"

(ii) Deborah's voice as she tells visiting professor "I taught the computer..."

(iii) Dan-Deborah situation -- as reported at project meeting, which had the quality of a clinical case discussion. Dan felt he was locked into a situation where her fear of not succeeding was manifested in an extremely dependent attitude in which she checked with him before making any move, even the simplest, leading him to spend a greater proportion of his time than he felt was appropriate. His strategy for dealing with that (out of the discussion) worked, in that she "learned to play", to "goof around" as she called it. She was "given permission to play".

4.4.2 Extract from Interview with Classroom Teachers at Lincoln School (George Hein)

Present: Lisa, Bob and Florence (teachers)

Did you notice anything particular, special with children as a result of the program?

B. -- Ray is again working with other kids. It's the first time he has this year. Wasn't at beginning of year, but is now.

They don't talk much in class about the LOGO

Did they talk at all about the LOGO project?

F. They did the first two days.
B. They have a positive attitude, it was a positive experience. Gary misses it painfully.
F. They all liked to go, the only one who missed sometimes was Jack. (Not one of our experimental subjects.)

L. - I listened for it, but there was little or no conversation. I wanted to have Gary work on a computer story, but he didn't want to. We did go down and see the work.

Were you surprized at the work anyone did? Did they perform as you might have expected?

B. I wasn't surprized. If I had seen the four sets of work I could have picked which was which. School work correlated closely with LOGO work, Gary became intense with it.

L. as he does in everything. I didn't learn much about learning styles. There was a breakthrough with Ray. It was very helpful... He hasn't connected all year, been floating, not that there is any resistance or hostility, built just no connection. He was well liked (by teachers) last year, but probably was swamped by the reading required this year. There was no initiative in his work the first two months.

The breakthrough for him in LOGO, the success he has had, is powerful information for me. I haven't really used it yet, but we have talked about it (Ray and Lisa) and he has produced the best piece of writing I've seen from him, including his work last year.

F. - Yes, something has happened for him this last week, he's smiling

B. - something since Christmas, that's for sure. Maybe he had a good Christmas.

L. - His physical arrangement has changed, he was isolated in the room before, now he sits with others.

L. - I was astonished at Deborah. Last year she was out of it, reclusive. Now she's taken off, is doing stuff, stays after school wants help. Maybe the breakthrough with the monogram on LOGO was what did it. we went skating, she showed stuff to her parents, had pride in it, wanted to share it. I'm not used to that.

F. - Their LOGO work was accurate (i.e. it matched school work) Monica for example, sticks to what she can do, does not try new stuff.

(I asked about Monica and Kathy)

They are not close friends in class. Each is willing to help others.

B. - It was good to see that Gary, given the lead, could show what he can do. The LOGO was a challenge to him, he could take it where he could go, not where the teacher wanted it to go.

L. - there is not enough room in school for him (*some talk about what would they do with Gary now, back in class)*

F. - We were disappointed that the kids didn't come up and share more. I can't get over it.

B. - I didn't build- in time for it

L. - there's not enough space in the day

F. - but if somebody is really excited about something they make time for it, we would have heard about it

L. - it would have helped if we had the print out sheets.

F. - we asked that stuff be brought up, we got nothing, it would have been nice to have even the notebooks.

F. - but the next group of kids are really anxious to go down

how do they know about it?

B. - true they must have talked about it

L. - we need visual stuff, but they are excited to leave the room. There's the freedom, they are sprung from the regimented program, it's cool stuff.

F. - how come we didn't hear about it?

B. - not public discussion, but they may have talked among themselves. The kids are eager to go.

. . . .

4.4.3 Comment on Deborah Based on Interview Material (Penny Dunning)

Deborah's presence in the pre-interview in November was one of a tentativeness, speaking softly, occasionally inaudibly, and looking downward, making no eye contact during the interview except to ask tentatively "is that right?" In the post-interviews of January there was some reduction in tentativeness and considerably greater eye contact.

What emerged predominantly in Deborah's pre-interview, compared with those in the post-interview, was a sense of defeatism when she was not able to determine the answer or do something right away. It is possible that a self consciousness with respect to mistakes increases the probability of mistakes and reduced her incentive to try harder or again. She was not challenged by difficulties and would not often yield to my encouragement to try, other than in a compliant manner, seeming not to connect with the content of the item or problem but providing only some form of response -- as in the exchange on my asking her if she could make a number pattern of her own to which she replied "no". She gave it a try on my request, writing numbers with no discernable pattern, although she had successfully completed some number patterns on the same exercise. She replied "no" to my question of whether she could fill in her own patterns. Scattered throughout the pre-interview are her statements "I can't", "I can't do it", and "I don't know". Is it that saying "I don't know" removes from any further responsibility to the question or problem? It is also interesting to note that she sees herself as one who "usually [has] help on things". Also in the pre-interview she seemed to be easily satisfied with guessing, as if a guess at least met the requirements, although she did not seem to concern herself with whether an answer had some relationship to the components of the item or problem.

With respect to the post-interview, there appeared to be less of a tendency to guess. It also is important to note that she hardly used the statement "I don't know" in the non-personal sections of the interview. Instead one finds statements "I have trouble with this" and "I don't get it". She was more responsive to my suggestions to try and seemed to engage herself with the challenge at hand rather than making a perfunctory and compliant effort.

There emerges a question as to how much and what kind of criteria does Deborah have for knowing when she knows. She seemed not to have any sense of what she would like to do better or of what she finds difficult to do. Does her guessing indicate that she doesn't know from where her knowing comes -- that is, from within her through her efforts to comprehend what is unknown -- or is it something that seems to fall in place, or already be known for some persons. She indicated that really paying attention and trying "my hardest" are the means to expanding her knowing. Yet these efforts seem to reflect her sense of outward expectations rather than an inner contact with her own powers for knowing. Likewise when she is stuck on something she seems unclear as to what she can do to get unstuck while still being connected to the matter she is stuck on. Certainly, if she has not become acquainted with her own inner criteria, there may be uncertainty, tentativeness, and self-consciousness, contributing to a greater awareness of one's mistakes that of one's accomplishments. She is not unable to appreciate when she has done something as in the geoboard exercises ("I did it") "Yup, I knew it was the other way", November interview) but the criteria was developed through the checks of what she had done with respect to the model given. It seems Deborah would be helped by having exercises structured where the criteria for correctness or satisfactory performance is developed within her through her powers of recognition rather than based on an adults' or fellow student's say-so.

A very important element that emerges from the post-interview is a change in Deborah's attitude toward "fun". Frequently Deborah speaks of things being "fun" or "funny" or "wierdest". She speaks of this most eloquently with respect to school: "sometimes its fun -- when I understand something and I like it" and as well as her LOGO experience, "everything was fun". Is she now developing an attitude of expecting more from her contact with her environment and her experience, that is, looking for what is fun? Her responses to the Tin Can question seemed to reflect more personal placement of herself with respect to the question, including a laugh when she suggested "you can step on them and walk on them" as if she were imagining herself doing just that.

It is this emerging sense of fun, of laughter of personal engagement that greatly alters my earlier impression of Deborah as a person passively and helplessly impacted by her experiences and by its demands on her.

5. Interviews

This presentation of the results on our interviews will be very brief. Our use of interviews has been exploratory. All interviews were carried out by Penny Dunning; their content was the outcome of many project meetings. We were interested in knowing more about our subjects, and many of the questions asked serve this function. We felt that it would be extremely unlikely that we would find changes in standardized I.Q. tests over such a short period, and considered that our best chance of success lay in exploring measures whose elements resembled, as much as possible, aspects of LOGO activity. An interview schedule excerpt is given in the Appendix. It includes number sequences; an embedded triangle task; creature cards; geoboard tasks; and 3 and 4 color permutations.

We decided to administer the interview schedule to all 16 subjects at the start of the experiment so that, should the post-LOGO interviews show any changes, we would have some chance of looking at "repeat testing" and "passage of time" factors. In actuality this tuned out to be the case. We found some interesting changes which appeared to represent more than just a regression effect, and so we re-administered some of the items to the second eight subjects who had not yet done any LOGO. In addition, we added some new items involving estimation of lengths and angle size, and map transversing instructions, which had not occurred to us to include in the initial interview design.

We have not yet had time to process this set of schedules, and so we cannot present our results as we would have liked to. Instead, we give the flavor of some of the findings.

1. A striking example of the overall tone and qualitiative aspects of the interview has already been quoted under "Affective Aspects" in Section 4.4.

2. In her pre-LOGO interview, Marilyn showed no obvious strategy in dealing with the permutation task; she found 5 out of the 6 possible 3-color permutations and 16 out of the 24 possible 4-color permutations. At the post-interview, she systematically found all 6 of the 3-color ones. In the 4-color task, she used definite but incomplete strategy and found only 12 of the possible permutations.

Kevin, who was classified by his teachers as below average in ability (his overall national percentile ranking was 31 on his most recently recorded achievement test) showed a great flair for LOGO. In particular, he was very comfortable handling angles from the start, estimating accurately, and learning to aggregate successive turns earlier than most other children. At the pre-LOGO interview, he performed poorly on number sequences, very poorly on both permutation tasks; in contrast he was very good at the geoboard exercise, involving as they do copying rotating and forming mirror images of shapes. After his LOGO experience, he improves considerably on all these tasks, including the Geoboard ones. The question of what to make of this finding is a somewhat knotty one. Perhaps it is all a result of his improved self-image?

6. Observer Activities

6.1. Use of Observers

At least one observer was present for two-thirds of the total number of LOGO sessions held. We used three types of observer-patterns:

1. Regular observations by consultant (Penny): 14 observation sessions, 6 during first fortnight, 4 during next three weeks, and 4 during last fortnight. Very detailed account of what went on, which includes comments on teacher pupil relations; on classroom dynamics and captures the occasional "moment of insight" --

> "When you want to make a right turn, you do 90"

A summary of these observations, made from Penny's notes by George Hein, is included below. (6.3)

2. Ocasional observations by consultant (George Hein): 4 observation events, a report on which is included below (6.2).

3. Observations by members of the LOGO group: one on an individual, regular basis, others as isolated visits (15 observation events in all). These contributed a familiarity with the subjects, necessary for writing this report.

6.2 Comments on Observing Dan Watt's LOGO classes at Lincoln School, Brookline November 30, 1977.

The following are impressions from the observation, not a record of events.

1. The power of the physical motion of "turtle" to understand the commands. In an early morning discussion between Dan and the two girls (Monica and Kathy) Dan asks what continual command of RT 15 would be. Monica only understands it after Dan has her get up and "play turtle".

2. The power of having the hcildren's work displayed both on the display tube and the display print out. As Dan goes from child to child he always has available both what they are doing now and what they have done in the immediate past. This is one of the few pedagogic situations where that is possible. (Perhaps it works in drawing class or some kinds of building activity) but usually you only have the students latest result and have to guess how the student arrived there.

But frequently, Dan can keep track of what a student is doing with whom he is not working, by glancing over or he can know what to ask, to correct, or to teach, by looking at what is displayed when he goes over to a student.

The same principle applies when a student asks a question. The questions are like all student questions, they refer to what the student thinks he/she wants to know. Dan can look over and say, "that's not the problem, the trouble is that you spelled X wrong in a command farther back." Or he can say, "It still won't work because of XYZ."

(My own classic model of the bizzare student question is always the model from chemistry lab, where the kid comes with the bent glass tubing and you have to resist the impulse to grab it because it is still hot enough to burn you. Even though it is held out to you, the student really wants to know where the rubber stoppers are, or something like that.)

In this lab, Dan automatically looks at the whole picture, or as much as is available on the screen and answers in terms of that.

3. The material that the children do provides the basis for tasks set the next day. The first class started with problems Dan had devised based on the girls' problems the day before. He gave them various routines which resulted in errors, first had them predict what would happen if they gave commands like

```
TO SLIP                      TO BLOOP
SLIP                         5 RT 15
END                          10 BLOOP
                             END
```

asked them to predict what would happen and then try it. It was a nice classroom exercise based on previous work. The analysis of previous work suggested appropriate problems for the students.

Note: Although Monica and Kathy were beginners, and had trouble predicting, etc. they already knew a lot. For example, Dan didn't tell them, but they know that to test out procedures like the above, they had to type in not only what was given, but then also to give the next command, SLIP or BLOOP to see what would happen. They already share a vocabulary and have some level of knowledge of how the computer works.

4. The children, especially the two above, use Dan's memory a lot. They must have somewhere a list of procedures (how do you edit, how do you modify, etc.) But they ask Dan. How necessary is this? Obviously, if they had to resort to looking up every item it would be like the child who "knows" mathematical operations, but doesn't remember any number "facts" and has to ask all the time what simple problems are. You can't get very much done that way. At the same time, should Dan always answer? He doesn't, and makes a decision in each case. Sometimes he will tell them to look it up, or to try things, etc. It takes a combination of expert knowledge on his part and decision on what to pass on. How much LOGO experience is necessary for the former and how much teaching experience for the latter? This is probably one of those open questions. The more of each you have, the better it is, but beginning teachers and relatively beginning LOGO folk could also do it. They would just not be as good until they got more experience.

5. There is a lot of activity which I would classify as "horizontal" learning. That is, the kids do a lot of repetitive stuff. Just as young children repeatedly pour the water in the funnel or sieve the sand over and over. Each time is a little different from the last, but they represent a family of very similar activities. Thus, the children draw similar circles, shapes, punch in similar commands, etc.

But on observation their work has very much the character of repetitive purposeful activity. They are attending, repeating with interest and presumably, storing up the necessary experiences to internalize the stuff they are doing.

Several times in my observation notes I comment that the concentration is intense. In the two classes I watched there was very little idle talk, seldom did a child get up or move around, except in the course of the work, no one left the room, they didn't even look at each others work. They were all concentrated. Monica tried to get Donald to do the BLOOP routine which leads to a "weird" result. "Donald, do BLOOP" "I can't I've got to do this." (He is trying to position the mouth in the face he is drawing.)

6. Dan's preparation (as well as his teaching technique) is impressive. He has prepared special activities for almost each child.

He gives the girls RCIRCLE, he has prepared an ARC command, he is already with a set of commands that will get to animation, etc.

7. There are a lot of "meta" questions from Dan. He forces the children to think about what they are doing, in a way that does not appear natural to these II year olds. "Why do you think I gave you these problems?" he asks the girls from the first group. "How will you know when it is there?" he asks Donald who is trying to position the turtle to draw the mouth. The teacher in the LOGO lab must know, not only, routines, but the reasons behind them in order to ask these sorts of questions. And his questions are more than the superficial, "what do you think will happen if..." that many teachers ask, they demonstarte that he has a purpose in mind in many of the tasks that he assigns, or he understands a purpose behind the actions of the children.

8. There is a nice mix of school tasks with the LOGO tasks. The children are obviously getting lots of exercise in writing and spelling (after all, correct spelling is crucial in talking to the computer, in a way that it is not in any other school task.) All these children can do this, which would not necessarily be true for all sixth graders. They have all mastered basic reading skills and writing skills.

Dan stresses to Monica that she must read carefully what the computer says. Another example of a typical school request from the teacher, but with a very specific reason. Often teachers correct minor reading errors from children, when the error does not change comprehension and therefore the child doesn't understand why he/she is corrected.

9. Whose values/interests predominate? Dan has a discussion with S------ in which he indicates to her that the designs she made previously are "slow" that they take a long time to draw out, and if she switched from circles to other geometric shapes they could be drawn much faster. I get the impression that the slowness bothers him, but not her. I don't think she even understood what he meant. In fact, she proceeds to draw one of her designs, contentedly watching the computer trace out a few circles. It is clear to me what Dan has in mind, but it is his, adult and computer-wize concern; not hers.

10. In the two classes that I watched, there was almost no interaction between (among) the students. Each worked separately on their own console. The only exception was the two girls, Monica and Kathy in the first class, who did problems together, but they, too, printed them out separately, and did not always check with each other. Perhaps the availability of all the terminals has something to do with it, but cooperative activity was not evident. Have they learned from each other's successes? I did not notice it during the one set of observations.

11. A wonderful computer geometry lesson. Ray wants to draw a triangle and has arrived at an angle of 117° to turn the line. Dan works with him and first the turn is made 115°. When Ray suggests that they try 119° next, Dan can't help but suggest that they try a "round number" and so they get to 120°. There is a lot of intervention from Dan in this whole episode, he introduced the idea of equal length of sides, etc. but that may be related to Ray's lack of general enthusiasm. But the final drawing of a perfect triangle by approximation, although not Platonic, does have classic qualities.

12. There is a wonderful opportunity for future teaching in S 's last creation, a series of nested squares which she develops by instructing the computer to draw SQ1, SQ2...all the way to SQ...40. The next lesson is obvious.

December 21, 1977

I seem to have some problems with names. In second class, one girl is Laura, I call her Suzanne.

1. The children have priorities and interests, they simply don't always fit with our ideas. An old bit of knowledge from watching and working with children but it came up today. Kathy puts both Dan and me in our place. She tells Dan that "I don't want a lot of Birdmen" when he is trying to sell the idea of writing an iterative procedure, and she tells me "there won't be a fourth one", when I expect her to repeat something again to make a symmetrical figure on the screen.

2. The children as teachers are fantastic. Not that they are good teachers, but what comes out.

> a. The children who come in are not totally naive; they clearly know some turtle commands, some ideas about LOGO.
>
> b. John's questions, especially, show a surprising knowledge of what the computer might do. He generalizes, sees problems and verbalizes issues. He sees what is wrong, and how to fix it, in principle, even though he doesn't know the specific commands.
>
> c. The session gives a good example of how much the regular kids have learned and how well they have learned it. General keyboard routine, basic commands, etc. are all clearly natural to them now. They are even impatient to teach these things, and simply correct the newcomers when they forget to leave out a space, or push the wrong key.

3. The pulling power of LOGO shows up again today. Even though the first class spent most of the time writing on the table, the second stayed and worked with a lot of people around. Laura dod not go to the play, etc. One also sees it with the new kids, the visitors. They literally said "Wow", "Gee" and other comic strip type words as they watched the things happen.

6.3 Notes on Penny Dunning's LOGO Observations -- George E. Hein, Lesley College

The observation notes do not provide a continuous record, but they do give some suggestive insights into what the children do and don't do in the class. The following are a collection of comments, not a sequential analysis. Any of them could be expanded or followed up through looking at the rest of the data.

Class I: Laura, Gary, Deborah, Ray

(numbers refer to page number for reference)

A. Vocabulary

The use of LOGO involves a complex, technical vocabulary. We may underestimate it, and underestimate just how much the children learn. "Log In" "It's reading the files" (2) and lots of other terms come up and, although they may have been explained, it takes time and experience to learn them. Ray asks why it is called "turtle" early on.

Later the children use words, but it is not clear that they always know what they mean.

B. What do 6th Graders Know?

1. Experiment vs. "messing about": Dan tells them to 'experiment' but it seems to me that they don't know what that means. This is not surprising from Piagetian work. When Dan suggests this; they often don't, then systematically try changing variables under controlled conditions. They do what Hawkins calls 'messing about'. The difference is important, and we can't expect the kids to get the kind of certainty from the latter activity that they would get from the former. Dan says, "experiment" and goes away. When he comes back Deborah or Ray may have tried some things, but they have not conceptualized the different results because they didn't consciously do experiments. (3/4)

2. Related to this [illegible] problem of scale. This has com up in several previous comments. If a line is 10 long, [illegible] much do you add if you want to make it a lot bigger? The kids obviously go at this problem in a messing about way, not an experimental way and without a clear sense of scale.

3. They have to do the "obvious". Laura does R50. After doing it she has no idea what L50 will look like (22). This happens repeatedly. What appears obvious to Dan, or other adult observers (or readers) is not obvious to the children.

4. Parts or procedures: What the children can do on the computer exceeds what they understand. In the various POLY procedures, they can generate designs, but they don't know what will happen if they change one number or the other, nor do they know the effect of each number on the pattern. Will it make the pattern bigger or smaller, wider or taller, generate faster or slower? They can only try it and then see, not comment on it a priori (964).

5. Output vs. procedure: There appears to be some confusion between instructing the computer to do something (Print or display a design) and teaching the computer (as the local lingo has it) a procedure. This is related to the vocabulary issue of how well the children understand the words they use. Laura uses the words, but does she understand? The same issue comes up again several times.

C. What do they do?

Related to the above are some issues about what the children actually do, in the context of their knowledge.

1. "Review" procedures. They spend a lot of time calling up procedures that they have done previously on the computer. This is graciously called "reviewing" procedures. Is it wasting time? Is it purposeful activity? Is it related to developing a working knowledge of the difference between generating a design and teaching the computer?

2. Deliberate erasure. Laura (25) and Ray (58) act in such a way that a design is not converted into a procedure. (I'm sure others do it also.) There are three possible explanations.

a. They don't realize what they are doing, i.e. don't understand.
b. They simply forgot in this case.
c. It's deliberate

I favor the last explanation, especially in Laura's instance. We should not underestimate the aesthetic element and just the element of will. The particular design was not what they wanted; there is a class notion that designs should be recorded; to avoid that the student does something "stupid" which will erase the procedure.

3. Check each other out: The kids regularly go over to watch what the others are doing. This activity follows a pattern through the observations. Of course when someone calls out or wants attention, they all look. But at other times, they just happen to look over at the other screens and just keep in touch with each other. There is probably a lot of learning that goes on this way.

D. The Value of LOGO

The items under B and C suggest to me certain particular values of LOGO as concurrent with the issues that have been raised.

1. "Messing about" Presumably kids need this experience., no matter what the medium in which they are working. LOGO provides a wonderful opportunity for this. It is very easy to mess about without making a mess! The infinity of numbers provides chances for variation, etc.

2. Repetition. The same applies here. Kids have to repeat to learn. (So do adults, that is why we often don't learn new skills, because we are not willing to put in the practice time.) LOGO offers a practical way to get this kind of experience. The observations clearly demonstrate that the kids do practice and repeat.

3. Trying the "obvious" The issue is mentioned above. The kids seem to have to try it, the other side of the coin is that LOGO provides the opportunity to try it and to see the results clearly.

4. Higher numbers: related is the topic of how much bigger, etc. gain, LOGO provides clear practice so that they can begin to realize that if 2 is small, 3 won't be much bigger and they should venture on to 20 or 200, etc.

5. The permanent record: Another example of the value of the trace which is left by LOGO Deborah bothers Dan a lot, and constantly asks for help. At one point she is stuck, he won't help and she goes off. (31) This time it really isn't something she could figure out herself, and Dan realizes this when he looks at what is on the screen. He can correct his behavior to meet the situation.

E. Ray:

He sure doesn't do much, but I am not clear why. There are some interesting aspects to Ray which come out from the observations. For instance, he can conceptualize; he suggests that if "x" is too hard to make for a tic-tac-toe game, other, simple markers can be used (44) and he can visulaize how an animation would work (44). He starts early with an idea of what he could do (in the first observation), and he spends a lot of time scheming how he could spend less time in the room than he has to. I don't know why he isn't more interested.

F. Finally, a nice quote (54)

Laura says, "My mother doesn't like computers. She thinks they're boring." Dan asks her, "Are they boring?" Laura responds, "Not when I'm doing it."

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Appendix I - Detailed Profiles of Each Child's Work

Individual Profiles: Gary

Gary was clearly the "brightest" child in the group. He had prior knowledge about using computers, and had done some programming in BASIC somewhere. Last summer he had attended a COMPUTERFAIR held in Boston, and had asked his parents to buy him a computer.

From the beginning he abosrbed ideas voraciously, and rarely had to be shown something twice. He was extremely eager to learn new things, and although he always stayed with a project until it reached some kind of completion, he seemed to have little desire to improve or alter a finished product. In one case, however, he completely reprogrammed one complex design at my request, as an exercise in "learning to write better programs").

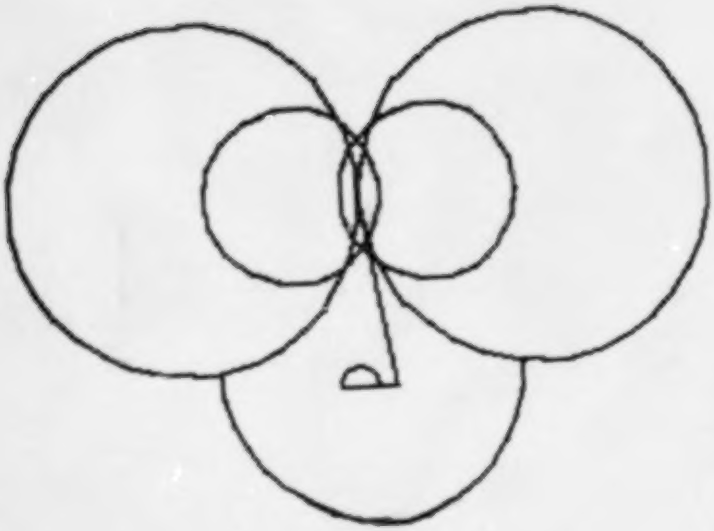
Gary regularly stayed "late" after the end of classes. He actually resisted leaving, to the point of making it an issue for a while.

A couple of major programming issues for gary were naming, and using functional subprocedures. Gary had a strong sense of humor, and enjoyed nonsensical names. He was introduced to the name FOO as a random procedure name, and decided to name all his procedures as a series of FOOs: FOOl, FOO2, ..FOO200. When he began working on his first big project to make a face using arcs and circles, he "buried" his functional procedures, FOO6, FOO7 and FOO8, inside procedures, which were inside other procedures. His procedures were somewhat involved, and required a fair amount of debugging...Gary had difficulty remembering whicb procedure he had to edit, and had a lot of confusion as a result. (See figure G-l)

Gary's general method of working, which persisted for a long time, was to plunge into a problem "headfirst", with very little planning, little consideration for the effects of an action that might go beyond what he was focusing on at the moment. As an example, in his second project, making a math quiz, he had a set of procedures named MATH, MATHl, MATH3. He decided that they were ordered incorrectly, and so decided to change the names of the procedures, so that the first procedure used would be MATHl, the second, MATH2, etc. What he forgot while doing this, was that he would also have to change all the procedures themselves, so that they would be calling the correct subprocedures. When he finished changing the names around, all his procedures suddenly stopped working. He was able to debug this situation himself by printing out his procedures and "playing computer". (See figure G-2)

Gary's third major project was the drawing and animation of a starship. His first attempt abandoned subprocedures in favor of a long, involved step-by-step construction. This led to some really involved, frustrating debugging. Gary plugged away at the process, which required that he add many lines to his one basic procedure.

Figure G-1



```
TO FACE
10 ENM
END
TO ENM
10 EN
20 M
END
```

```
TO EN
1 EYES
2 NOSE
END
```

```
TO M
1 MOUTH
END
```

```
TO EYES
1 FOO6
END
```

```
TO NOSE

1 FOO7
END
```

```
TO MOUTH
10 FOO8
END
```

```
TO FOO6
1 FOO5
2 PENUP
3 LEFT 90
4 FORWARD 80
5 PENDOWN
6 RIGHT 90
7 RCIRCLE 45
8 PENUP
9 RIGHT 90
10 FORWARD 160
11 LEFT 90
12 PENDOWN
13 LCIRCLE 45
14 HIDETURTLE
END
TO FOO5
1 LCIRCLE 90
2 RCIRCLE 90
END
```

```
TO FOO7
1 PENDOWN
2 S
3 FORWARD 100
4 RIGHT 99
5 FORWARD 30
6 RIGHT 90
7 RARC 10
8 RARC 10
9 HIDETURTLE
END
TO S
6
10 PENUP
20 SHOWTURTLE
30 LEFT 90
40 FORWARD 80
50 LEFT 90
60 LEFT 9
70 PENDOWN
END
```

```
TO FOO8
1 PENUP
10 PENUP
20 FORWARD 70
30 PENDOWN
40 RIGHT 90
45 RARC 80
50 PENUP
55 RIGHT 90
60 FORWARD 166
70 RIGHT 90
80 FORWARD 70
90 LEFT 90
100 PENDOWN
110 LARC 80
120 HIDETURTLE
END
```

Figure G-2

```
TO MATH
10 PRINT [WOULD YOU LIKE TO HAVE A MATH TEST?]
15 MAKE "ANS REQUEST
20 IF :ANS = [YES] PRINT [WELCOME TO THE WORLD OF MATH!] MATH1 STOP
30 IF :ANS = [NO] PRINT [O. K.  COME BACK AGAIN!] STOP
END
TO MATH1
5 MAKE "NUM1 WORD RANDOM RANDOM
6 IF FIRST :NUM1 = 0 GO 5
7 MAKE "NUM2 WORD RANDOM RANDOM
8 IF FIRST :NUM2 = 0 GO 7
10 PRINT ( SENTENCE [%%] :NUM1 )
15 PRINT [+]
20 PRINT ( SENTENCE [%%] :NUM2 )
21 PRINT [________]
25 MAKE "ANS TYPEIN
30 TEST :ANS = :NUM1 + :NUM2
40 IFTRUE PRINT [CORRECT!] MATH2 STOP
50 IFFALSE PRINT [TRY AGAIN!]
60 GO 10
END
TO MATH2
10 PRINT [WOULD YOU LIKE TO HAVE ANOTHER PROBLEM?]
20 MAKE "ANS REQUEST
30 IF :ANS = [YES] PRINT [O. K. HERE WE GO AGAIN!] MATH1 STOP
40 IF :ANS = [NO] PRINT [ALL RIGHT. SEE YOU NEXT TIME!] STOP
END
TO MATH3
5 PRINT [WELCOME TO THE WORLD OF MATH!]
10 PRINT [17 + 28=]
20 MAKE "ANS TYPEIN
30 TEST :ANS = 17 + 28
40 IFTRUE PRINT [CORRECT!] STOP
50 IFFALSE PRINT [TRY AGAIN. ]
60 GO 10
END
```

> (He had used a HOME command in his original starship plan to reset the turtle at several points during the procedure. Since this ruined the animation, all the HOME commands had to be eliminated, and, to carry through with the plan, replaced by several steps which would bring the turtle back to the origin.)

Following Gary's successful completion of this task, which had taken him about an hour, during which he needed help understanding the initial bug, I explained to him that a "good computer program" would be simple, and easy to understand. That with a few simple subprocedures he could have made a starship program that was much easier to understand and debug. I suggested that he re-do his starship from scratch next time, and try to make it really simple. He agreed to this, and next time made a starship program using modular subprocedures, that could almost serve as a kind of model of LOGO programming. (It still had some sub-procedures contained within others, contained within others, which made it a bit more compelx that it had to be.) The exciting thing was that for the first time, Gary understood what it meant to write a "good program" and was able to reflect a bit on organization vs. dis-organization. (Gary also cleaned up his notebook, put the pages in order, etc. -- another suggestion from me that he was willing to accept and understand, at this point.) (See figure G-3)

From the start, Gary displayed absolute confidence that with my help, he could make the computer do anything he wanted. For his last project, he decided to use an idea he got from a "creative computing" pamphlet which described a "science project" by a clever high school student who combined a morse code reading program with a discovery that a certain kind of repeating loop program caused interference in a nearby AM radio. By controlling the running time of the looping procedure, he was able to produce "dot" and "dash" interference on the radio and hence use the computer to transmit an audible morse code. Gary very much wanted to do this project, and even brought in an AM radio for it.

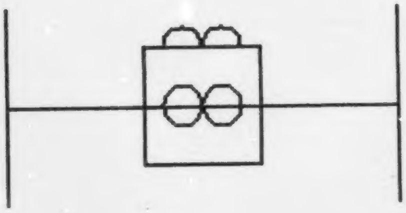
Despite my protestations that I didn't know how to do it, Gary was determined and convinced that he (and I) could do it. He did realize that it was a big project, and might not be accomplished completely in the time we had left. He also agreed to my suggestion that he begin with a program that could translate sentences into morse code, and a reverse program to translate morse code into sentences. He realized that these would have to be a basis for his larger project, and was content to begin modestly.

For the final two classes, Gary had a visitor, his friend John, a seventh grader. His interactions with John were very suggestive about what might have been possible for Gary in a less restricted learning environment. (that is -- more people for him to interact with fruitfully) John caught on to the elements of LOGO extremely quickly under Gary's tutilage. At the same time he supplied a sense of "creativity" that Gary was lacking in his approach to the work. Two examples that I picked up and referred to in my notes of the last session:

Figure G-3

OLD STARSHIP PROCEDURES

```
TO STARSHIP
10 RIGHT 90
20 FORWARD 100
30 LEFT 90
40 FORWARD 50
50 RIGHT 180
60 FORWARD 100
70 PENUP
71 LEFT 180
72 FORWARD 50
73 LEFT 90
74 FORWARD 100
75 RIGHT 90
90 LEFT 90
95 PENDOWN
100 FORWARD 100
105 RIGHT 90
110 FORWARD 50
120 LEFT 180
130 FORWARD 100
140 PENUP
141 RIGHT 180
142 FORWARD 50
143 RIGHT 90
144 FORWARD 100
150 LEFT 90
155 PENDOWN
160 RIGHT 90
170 FORWARD 30
180 LEFT 90
190 FORWARD 30
200 LEFT 90
210 FORWARD 60
220 LEFT 90
230 FORWARD 60
240 LEFT 90
250 FORWARD 60
260 LEFT 90
270 FORWARD 30
280 PENUP
290 LEFT 90
291 FORWARD 30
292 RIGHT 90
300 HIDETURTLE
310 PENDOWN
320 RCIRCLE 10
330 LCIRCLE 10
340 PENUP FORWARD 30
345 PENDOWN
350 RARC 10
360 RARC 10
370 PENUP RARC 10
380 RARC 10
390 LARC 10
400 LARC 10
410 HIDETURTLE
END
```



STARSHIP

NEW STARSHIP PROCEDURES

```
TO STARSHIP
10 STA
20 WINGR
30 WINGL
END
```

```
TO STA
5 WRAP
10 C
20 LI 100
END
```

```
TO WINGR
10 MO
20 RIGHT 90
30 LI 50
35 LEFT 90
40 MOV
END
```

```
TO WINGL
10 MOV
20 LEFT 90
30 LI 50
35 RIGHT 90
40 HIDETURTLE
END
```

```
TO MO
10 RIGHT 90
20 FORWARD 100
30 LEFT 90
END
```

```
TO MOV
10 LEFT 90
20 FORWARD 100
30 RIGHT 90
END
```

```
TO C
10 SQ.1
20 PENDOWN RCIRCLE 10
30 LCIRCLE 10
40 PENUP FORWARD 30
45 PENDOWN
50 REPEAT [RARC 10] 2
60 PENUP REPEAT [RARC 10] 2
70 PENDOWN REPEAT [LARC 10] 2
80 PENUP REPEAT [LARC 10] 2
90 BACK 30
END
```

```
TO LI :LE
5 PENDOWN
10 RIGHT 90
20 FORWARD :LE
30 LEFT 180
40 FORWARD 2 * :LE
50 RIGHT 180
60 FORWARD :LE
70 LEFT 90
END
```

(1) the boys were animating a "zeppelin" which was oriented horizontally. Whenever it "flew" it always moved perpendicular to the longitudinal axis. "Hey", John said at one point, "what if we turned the zeppelin 90 degrees first -- then would it fly in the right direction?" Of course -- exactly the right solution. [Gary might never have come to it as quickly.]

(2) similarly, the boys built a maze on the screen, and realized that the Zepplin was too big to animate. John suggested animating the "turtle" an idea that astounded GEM. (After all, the turtle was "the turtle") Gary had the conceptual tools to animate the turtle easily with a few words with me. John had the divergent thought processes to suggest entirely different ideas, outside of gary's usual framework.

What might have happened if both had been in the class together from the start -- or if gary's class environment had been such that he could have been exposed to a variety of creative inputs from peers. This suggests strongly that the ultimate place for the computer is in the classroom, rather than in the "computer lab".

Individual Profiles; Kevin

Kevin was an able and enthusiastic student. From the beginning he had an exceptional ability to control the turtle -- quick with accurate estimations, changing or combining steps with confidence. Kevin was the first student in his group to see that a turn of 90 degres was necessary to make a box; the first to see that RT 90, RT 90, could be replaced by one instruction, RT 180 which would always turn the turtle around. Kevin was also very quick to combine FOWARD commands. He rapidly learned to shift the position of his head, to parallel the position of the turtle, in order to decide which direction to turn it. In general, the world of the turtle was a very comfortable one for him.

Kevin was a compulsive note taker. He took notes as he worked, and then recopied them, so that they would be "neat" in his notebook. When the children all worked as a group for the first four classes, Kevin was the first to take on the role of "recorder". At the end of the first day, after the group had made the turtle draw a box, but had not yet learned how to write a procedure, Kevin wrote down the steps in his notebook, so that they could be remembered:

```
TO MAKE A SQUARE

FD 100
RT 100
LT 20
RT 10
X
3
```

In his project work, Kevin made a great effort to finish everything he started (with the exception of a very complicated "flag" which he abandoned). He was willing to experiment patiently, and when something did not work out exactly right, start again. He took careful notes of successful steps, enabling him to start easily from where he had left off.

Kevin was very responsive to suggestions from the teacher. He seemed to absorb new ideas quickly, when they were relevant to his work and to his existing sense of how things could be done. In the same way that Kevin automatically combined steps to rewrite FD 50, FD 50, as FD 100, the next time he wrote it, or RT 90, RT 45 as RT 135, he seemed to be extremely quick to seek out and accept other ideas that led to shortcuts, or streamlining in his work.

Kevin had a linear approach to problem solving. He liked to approach his tasks one step at a time, in order. Advance planning was not his specialty. Although he did learn to use subprocedures within a larger project, when he had one part that was repeated over and over, or when he needed to break up his work into manageable chunks, he was never interested in "top down" planning, in which he would have had to decide in advance which subprocedures he wanted to use, and how to organize them.

Kevin's work during the series of classes can be divided into five major segments. During sessions 1-4 he worked with the entire group, learning the basics of LOGO by developing some designs involving squares. Sessions 5 and 6 were spent inventing a triangle procedure, and creating other shapes using the triangle. Sessions 7 and 9 were devoted to a complex flag project which Kevin decided to drop. In session 10, he began a major project -- making the computer draw and then animate a large turtle. This project was continued for a period of two weeks, and was worked on for the major part of 6 different classes. During his last three working sessions, Kevin worked with POLY procedures, exploring angles, shapes, variables and stop rules.

During the first four classes, Kevin took a lot of leadership, as the class worked together on a series of projects involving boxes. Kevin suggested ideas for projects, names for projects, and was especially helpful in suggesting the steps needed to carry out the projects. It was only when the teacher suggested that one of the projects be carried out in a "top down" "plan-ahead" manner, that Kevin had difficulty understanding what was happening, and how to proceed.

During the first four classes, Kevin demonstrated again and again a quick, intuitive grasp of the world of the turtle. While he seemed to have a good sense of what step should be taken next -- especially where the turtle should be aimed -- he was not always able to decide how far the turtle should go. He also had difficulty knowing exactly where the BOX procedure would appear on the screen when it was used.

His intuitive grasp of Turtle Geometry became even more apparent during his first independent project -- making a triangle. His very first attempt was RT 45, FD 100, RT 45, RT 45, FD 100, producing the figure shown.

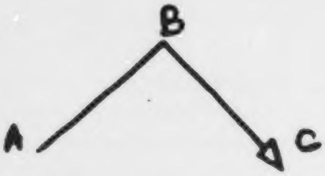


figure Ke-1

He needed two tries, experimenting with the angle at point C, before hitting on RT 45, RT 40, RT 50, which he first combined to RT 45, RT 90, and then to RT 135, when he wrote the procedure. He easily estimated the distance to close the triangle as 150, then went BK 10, and changed the total to FD 140 in his procedure. Kevin's triangle procedure, arrived at in about 25 minutes of exploration was:

```
TO OF
1 RT 45
2 FD 100
3 RT 90
4 FD 100
5 RT 135
6 FD 140
END
```

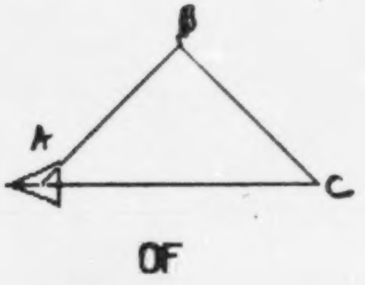
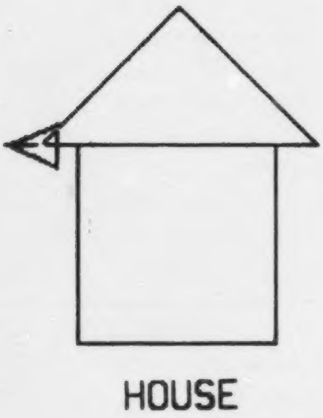


figure Ke-2

When Kevin repeated OF, it made a flower-like design. He also used his OF procedure, along with BOX, to make his own version of a house, and a row of two houses.



```
TO HOUSE
1 BOX
2 RIGHT 90
3 FORWARD 100
4 LEFT 90
5 FORWARD 20
6 RIGHT 90
7 OF
END

TO 2HOUSE
1 HOUSE
2 PENUP
3 FORWARD 100
4 RIGHT 90
5 LEFT 180
6 FORWARD 100
7 RIGHT 90
8 FORWARD 50
9 RIGHT 90
10 PENDOWN
11 HOUSE
END
```

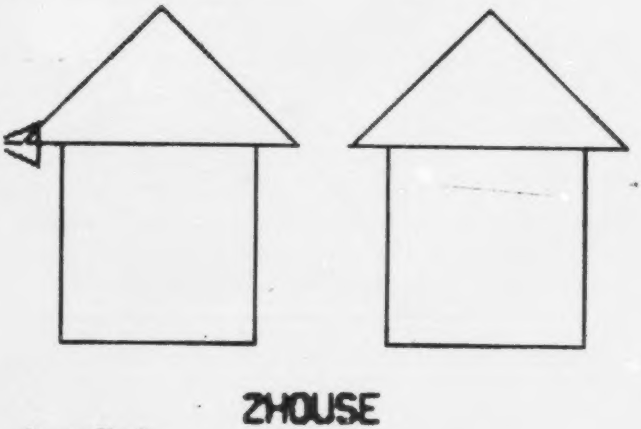


figure Ke-3

Kevin's next project was to make a large American Flag. His flag was worked out as along sequence of steps. It was based on the procedure BIGBOX, which provided a background of 100 by 100 squares in a 4 by 3 grid. Kevin used the boxes of the grid as markers, as a kind of "coordinate system," so that he could tell how long the stripes should be. The flag, which Kevin worked out experimentally by direct command, looked something like this:

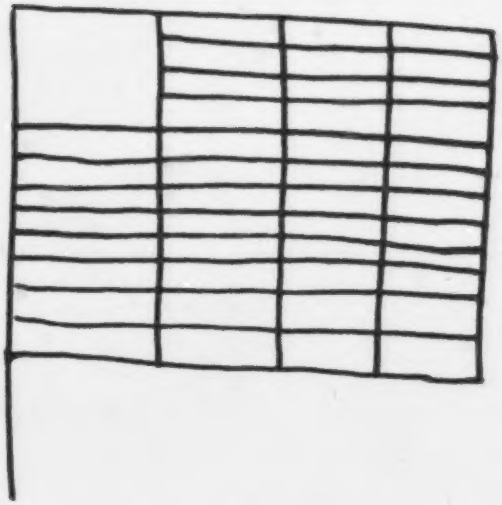


figure Ke-4

Kevin took careful notes, and attempted to write down each successful step in his notebook. Unfortunately, there were many steps, and Kevin had made a few mistakes in copying. The process of debugging the incorrect steps, and restoring correct ones seemed too formidable to Kevin, and he decided to abandon the project. I tried to use the situation to suggest a different approach: plan out the project, using subprocedures for the long and short stripes, etc., Somehow, Kevin did not understand this approach. Or he did not want to "shift gears" and start over. He preferred to drop the project -- the only time Kevin ever gave up on anything he started.

Next, Kevin began what became his major project -- lasting for six classes, over a two week period. This time, he did a certain amount of advance planning. First he drew a picture of what he wanted the turtle to look like (figure Ke-5), and started right in to build it, using arc and circle commands. This time, Kevin was willing to work in terms of subprocedures: SHELL, HEAD and FOOT (at my suggestion), but his approach to building the turtle was still sequential -- a step by step process.

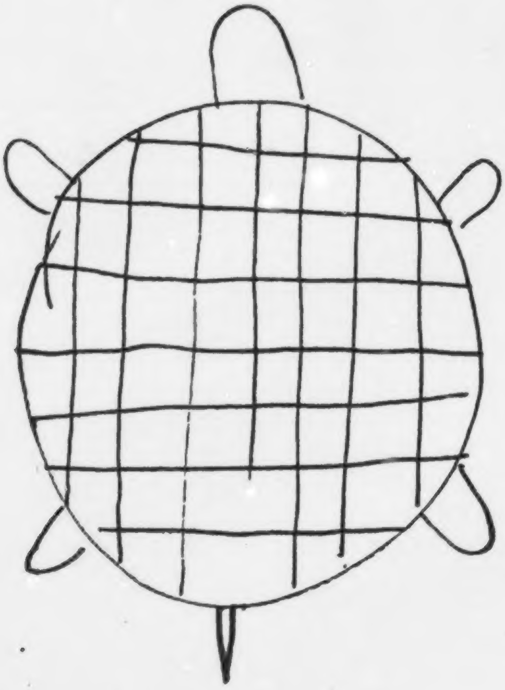
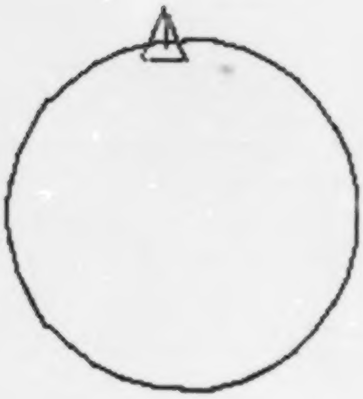


figure Ke-5

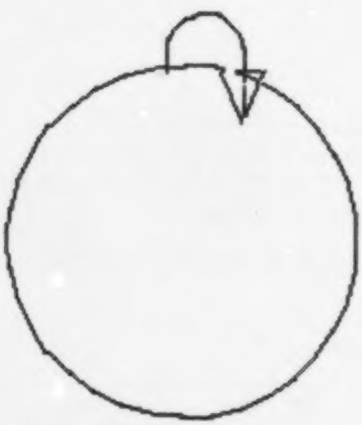
While working on this project, Kevin had to absorb a lot of new techniques. He became expert in the use of PENUP mode for explorations. He learned to use RARC :R and LARC:R with precision, carrying out careful explorations with the turtle's PEN UP by using, for example, RARC 90, followed by RT 180, LARC 90, RT 180. I also showed Kevin an arc procedure with a variable angle, ARCR :R :A and ARCL :R :A, so that Kevin could easily move the turtle around the circle which formed his "turtle's" outer shell. As he had done for the flag project, Kevin invented his own coordinate system to aid him in moving around the outer shell. The 3500 display system leaves a dot after each individual step. The circle procedures which I gave Kevin used angles of 10 degrees as the basic step. Kevin discovered by experimentation, that ARCR 90 60, for example, would move the turtle exactly six dots along the outer circle. In this way, Kevin as able to navigate the turtle around the SHELL in a precise manner, to locate the four feet, and the tail, in precise relation to the head and each other.

Kevin now had another problem -- getting the turtle back on the SHELL, after each subprocedure. After completing the HEAD, for example, Kevin had experimented with turning the turtle through different angles, to line it up with the shell again. Then he moved on down to make the first foot. Now he turned the turtle LT 90, and made a FOOT, at which point he had the problem of getting the turtle back on the shell again.

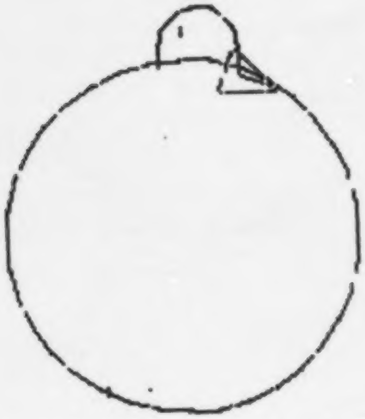
Figure Ke-6



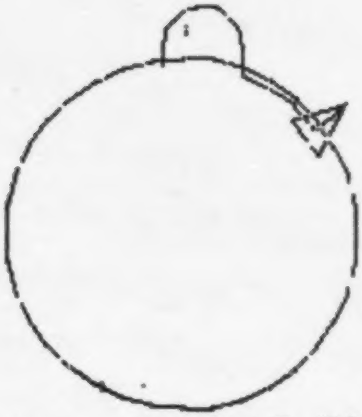
SHELL



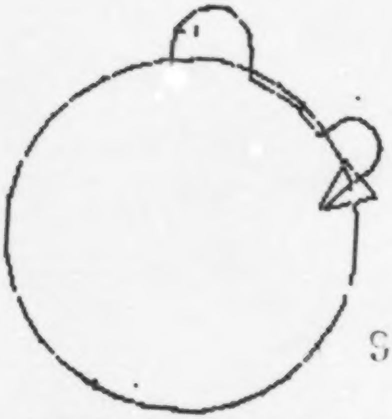
SHELL HEAD



SHELL HEAD LT 70

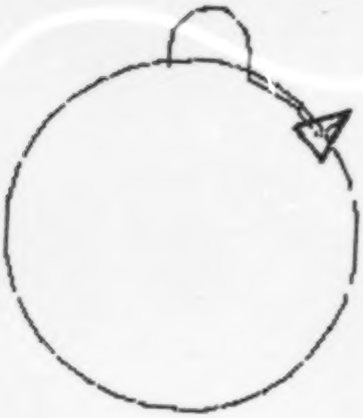


SHELL HEAD LT 70
ARCR 90 30 LT 90



SHELL HEAD LT 70
ARCR 90 30 LT 90 FOOT

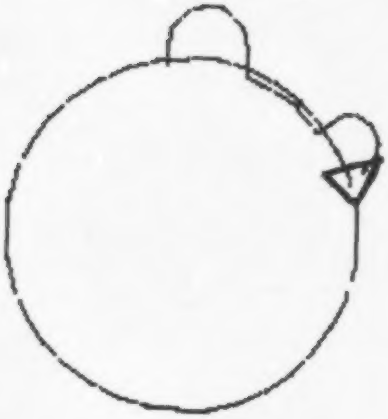
Figure Ke-7



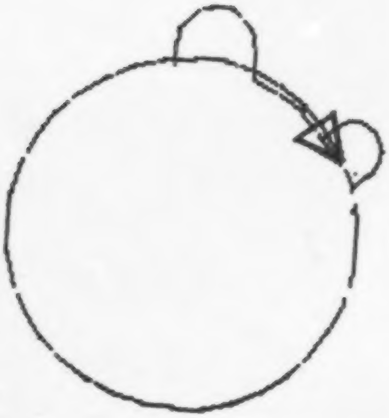
SHELL

HEAD LT 70 ARCR 50 30

LT 90



FOOT RT 180



BKFOOT LT 90

At this point I showed Kevin that if he changed his FOOT procedure, so that it finished exactly where it started, he could just turn the turtle 90 degrees, and it would be precisely back on the circle again. I also explained that the simplest way to get the turtle back to its starting place was to reverse the steps of FOOT. Kevin understood the usefulness of my idea, and used it in his own way. Rather than add the extra steps to FOOT, Kevin created a new procedure, BKFOOT:

```
TO FOOT                         TO BKFOOT
10 RARC 20                      20 LARC 20
15 RARC 20                      30 LARC 20
20 FD 11                        40 FD 8
END                             END
```

In this way, Kevin could move along the circle until he came to the point where a FOOT was wanted. He would then use the following sequence: LT 90, FOOT, RT 180, BKFOOT, LT 90. This would locate the turtle exactly where it had been before making the FOOT, ready to continue its journey around the SHELL. (figure Ke-7)

I have discussed this example in detail, because it gives a good sense of how well Kevin absorbed new ideas, at the moment that he needed them, as long as they fit into the basic approach he was using. He rejected the idea of making the FOOT procedure itself state transparent (my idea), but used it in his own way for exactly the same purpose. Once he adopted the idea, he used it expertly, without hesitation. It was then fairly easy for him to complete the turtle (figure Ke-8). He had abandoned the idea of making lines across the shell.

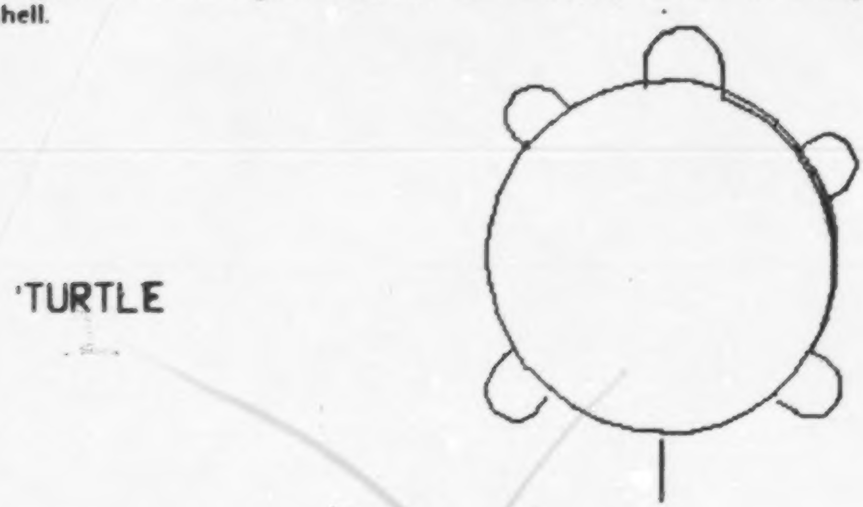


Figure Ke-8

Completion of Kevin's turtle was followed by an attempt to animate it using SNAPs. This was not as successful, partly due to my inexperience in using the 3500 for animation; partly due to display storage limitations.

Kevin's last area of work involved POLY procedures and variables. I showed Kevin a POLY :SIDE :ANGLE procedure, and after he had played with it for a while, I suggested that he keep the angle input constant, while varying the size. He then tried a series of POLYs with an angle of 45 degrees. POLY 50 45; POLY 55 45...POLY 110 45. This made a design that Kevin called a "tunnel". We talked through the procedure

```
TO TUNNEL :SIZE
10 POLY :SIZE 45
20 IF :SIZE = 105 STOP
30 TUNNEL :SIZE + 5
END
```

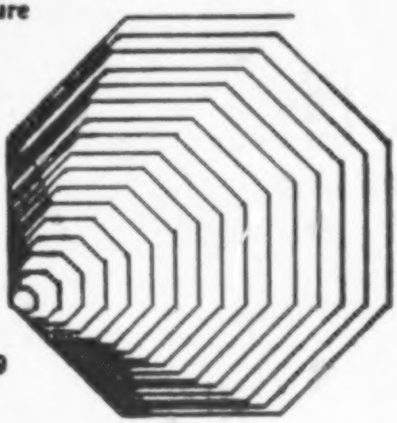


figure Ke-9

During the next class, Kevin made a great leap in understanding the use of variables. He experimented with varying the size of a POLY whose angle was 90. Then, with some help from me, he wrote the procedure:

```
TO LIFS :SIZE
10 POLY :SIZE 90
20 IF :SIZE =150 STOP
30 LIFS :SIZE + 2
END
```

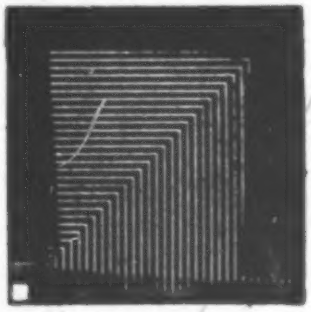


figure Ke-10

He then decided that the step of + 2 in LIFS was too small. By himself, he wrote the procedure:

```
TO FU :SIZE
10 POLY :SIZE 90
20 IF :SIZE = 150 STOP
30 FU :SIZE  + 5
END
```

At this point, I told Kevin that I could show him how to make it possible to "change the amount that the POLYs would grow each time, by making that a variable. He picked the name "SET for the new variable, and together we wrote the procedure:

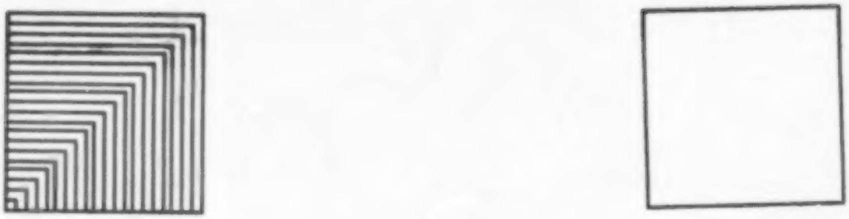
```
TO UFC :SIZE :SET
10 POLY :SIZE 90
20 IF :SIZE = 150 STOP
30 UFC :SIZE + :SET :SET
END
```

At first Kevin was confused about the appearance of :SET twice in the recusion line, but I explained that the first time it was added to :SIZE to give the new :SIZE, and the second time it was telling the computer to keep track of the variable "SET.

Then, before we could try out UFC, Kevin asked, "Could we make the largest size change, too?" "Of course," I said, "What do you want to call it? He decided to call it "LARGE, and we edited UFC. Kevin knew that :LARGE had to be added to line 30, and that line 20 had to be changed to read IF :SIZE = :LARGE STOP. Kevin spent the rest of the period experimenting with UFC.

```
TO UFC :SIZE :SET :LARGE
10 POLY :SIZE 90
20 IF :SIZE = :LARGE STOP
30 UFC :SIZE + :SET :SET :LARGE
END
```

Kevin could now vary the starting size, the ending size, and the rate of growth. He tried a number of experiments, but none that would produce a stop rule bug (for example UFC 10 2 25) would never have its stop rule satisfied). His favorite discovery was that UFC 100 100 100 made one square of side 100. He was thrilled to realize that he could use this to make a variable sized square procedure. He did not realize that his middle variable was now irrelevant although he did understand that the reason only one square was made was that the starting size and the ending size were the same.



UFC 5 5 100

UFC 100 100 100

Figure Ke-11

During these sessions, Kevin demonstrated the same quick learning in the use of variables, that he had shown with regard to turtle geometry. I believed that this happened because he was <u>using</u> these elements, manipulating them to achieve a purpose. Always ready to absorb an easier way of doing something, Kevin was able to make a leap in understanding that he had not achieved earlier, when I had introduced the idea of variables and stop rules as a little "lesson" for the whole group.

For the next to last class, Kevin invited Frankie to be his visitor. He began by showing Frankie some of his procedures. He then taught Frankie some of the elements of LOGO. First he created a model of what he was trying to show, then let Frankie try it out. For example, to teach Frankie how to write a procedure, Kevin wrote:

```
TO ACE
10 POLY 90 45
END
```

He then let Frankie make up his own procedures based on this idea, and try it out. Frankie wrote:

```
TO KISS
10 POLY 7 50
END
```

Then they worked together on a little project -- to make the computer draw the "kiss" design (shown at left), a copy of the design on Frankie's T-shirt. They worked through the design, step by step, with Kevin doing the typing, and Frankie taking notes. Kevin and Frankie discussed each step of the process. The project involved forward and back, right and left, penup and pendown commands, and used rotations of 45 and 90 degrees. The period ended before they could "teach" their design to the computer.

Kevin began the series of classes with a very strong and accurate sense of how to control the <u>turtle</u>. He did not originally show the same sureness in using the <u>computer</u> as a tool to organize and simplify his work. Through work on his turtle project, he began to use the idea of subprocedures, and state transparent designs to simplify his work. By the end of the series of classes he had assimilated the idea of using variables to control the size and shape of repeated POLY designs, and to control the procedure itself. Thus he had moved in his work from using the computer to control the turtle, to learning to control the computer itself.

Individual Profiles; Donald

Donald is a student whose work was characterized by a good understanding of formal approaches to problem solving, combined with some difficulty with details of geometry. He was especially good at naming procedures and subprocedures, using and understanding top-down planning, making use of mathematical analysis in planning his work, and understanding the function of conditionals and stop rules. At the same time, he tended to have difficulties when working "experimentally", with turtle geometry -- often not quite sure where the turtle would move next.

Donald spent most of his class time on one project: making the computer draw an elaborate HEAD, which included a beard, hair, a hat and a flower, in addition to the usual features -- eyes, ears, nose and mouth. Donald worked for twelve class periods on this project. He began by drawing a picture of what he wanted the head to look like, and following the teacher's suggestion, wrote out a super procedure to draw the head, using subprocedures to add each of the features. In the course of his work, Donald had to do a great deal of estimating, of both distances and angles, use arc and circle procedures, use procedures that repeat, use variables to control size and angles, and especially, learn to separate a problem into parts, to make it easier to solve. In addition, he used a POLY procedure to make a FLOWER for his head, and had to use recursion, as well as a conditional stop rule.

Throughout his work, Donald had difficulty in understanding the effect of the state of the turtle at any given time. He could not always predict where the next step would occur. At times it seemed as if Donald had some difficulty in seeing exactly where the turtle was headed. The teaching strategy employed to help Donald deal with these problems, was to help him develop tools of mathematical analysis, to help him figure out the best way to aim the turtle, without relying totally on experimentation. In this way he was exposed to the idea of using a kind of "grid" to help him maneuver the turtle around his HEAD, and to the way in which the total angle turned by the turtle in a given situation, was a key to deciding how much farther he had to turn it next. In addition, he was shown how to break up even a small problem into parts -- for example, in placing a mouth on his face, he had to decide which arc to use for the mouth, the orientation of the turtle, and the starting point for the mouth. In this way, he was helped to overcome obstacles that might have interfered with his success while learning principles of geometry, computer programming, design and planning.

Donald's first problem when he began to work on his own, was to make a "house", using a triangle and a box. He had developed the BOX procedure on the first day of classes, along with the rest of the kids, but he had been absent during two classes when the children all defined triangles. Donald was given a state transparent procedure which produced a triangle like this:

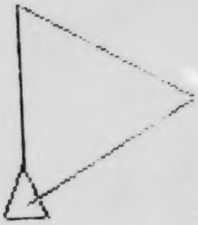


Figure D-1

Donald spent the entire period trying to add the BOX to it, like this:

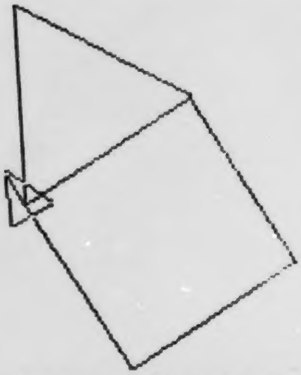


Figure D-2

His basic strategy was to try to get the turtle to the upper right hand corner of the triangle, and then use the BOX procedure. (BOX made a square by turning right.) He never succeeded in figuring out how far to turn the turtle to get it to the right place. Although he came close to it by experimentation, he had not kept adequate notes, and so, did not realize how close he was. Part of the problem was that he was dealing with two disorientations — the problem of the "gap" between the TRI and BOX procedures, and the tilted orientation of the whole shape. When I suggested that Donald make a plan by drawing a picture of the house he was trying to construct, he drew a tilted house!

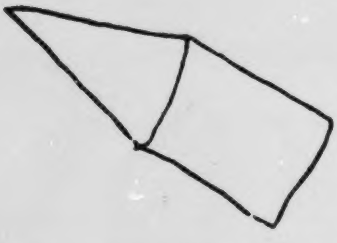


Figure D-3

I began the next class by suggesting that he begin with the BOX (to eliminate the disorientation of tilting). Once he did this, he figured out a way to solve the "gap" problem, without having to find the angle between the BOX and the triangle. He simply moved the turtle to the upper right hand corner of the BOX, turned it around, and used the TRI procedure, so that the first leg of the triangle was along the top of the BOX.

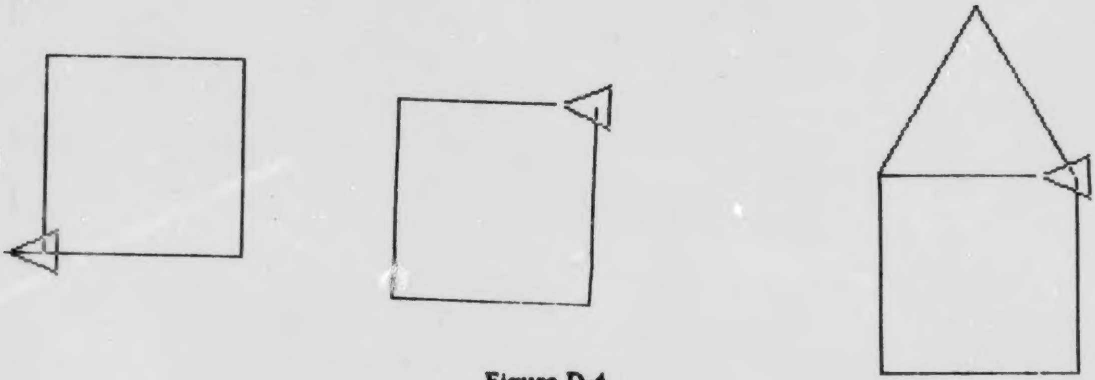


Figure D-4

After experimentation he made a mistake in copying steps, and I had to help him debug his HOUSE procedure, by comparing steps on the screen with steps in his procedure. I suggested that he get in the habit of writing the correct steps in his notebook, so that he would have a record from which to copy.

After a couple of classes, during which he experimented somewhat randomly (working on a "train" and a "city" neither of which was ever made into a procedure), Donald settled on an idea which was to become his major project for the next four weeks. He decided to make a man's face, complete with beard, hair, hat and flower. He drew the following picture in his notebook at the beginning of session 9, on November 23rd.

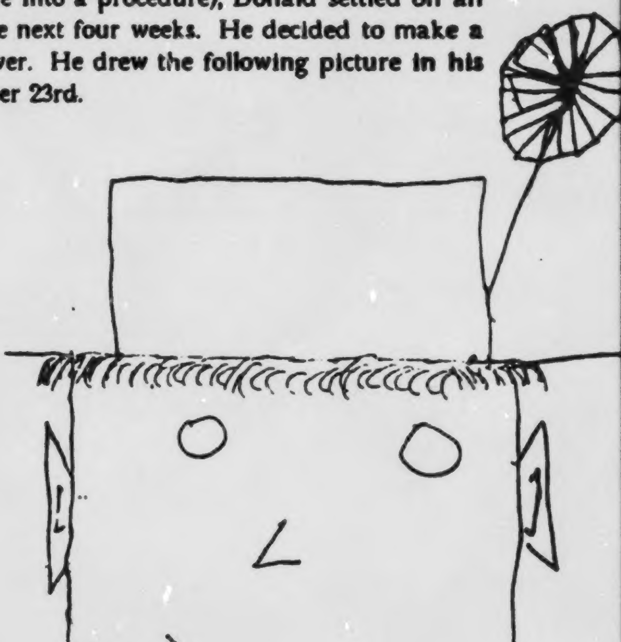


Figure D-5

By November 28th, he had modified his plan somewhat, and drew this picture, which simplified the ears and the hair, but added a moustache:

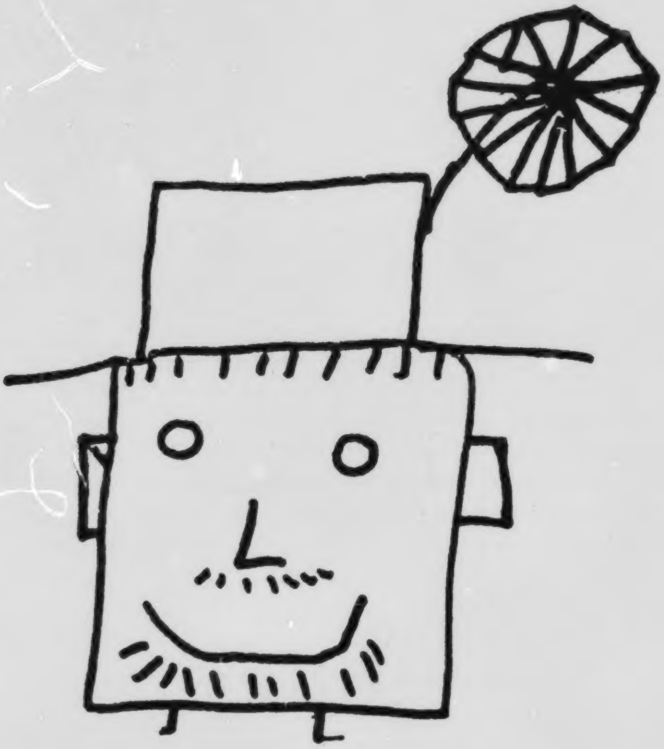


Figure D-6

He worked steadily on this project until it was completed in session 21, on December 19th. He had worked for 12 separate class sessions on his head. The result was almost exactly like his second plan (without the moustache):

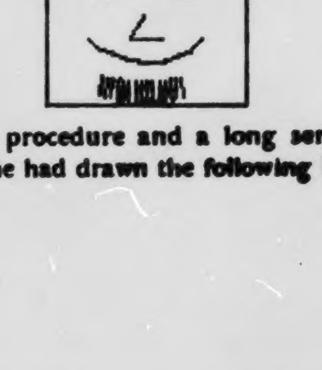


Figure D-7

He began serious work in session 9. Using the BOX procedure and a long series of individual steps, (which he wrote down in his notebook) he had drawn the following by the end of the period:

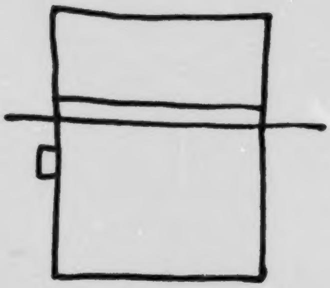


Figure D-8

I showed him how to make a variable sized box procedure, so that he could experiment easily with the size of the hat (I thought he might be able to use it for the ears, too).

At the beginning of class 10, I suggested to Donald that he make a plan for the head by writing a superprocedure which would include all the parts of his head. Then he could teach the parts, one at a time, and simplify the whole process. Donald understood this immediately, and together we wrote the procedure HEAD:

```
TO HEAD
1 BOX
2 EYES
3 NOSE
4 MOUTH
5 BEARD
6 HAIR
END
```

During the same class Donald completed the procedures for making the eyes and the nose. To help him figure out how to place these features within the head, I helped him work out a sort of "coordinate system" or "grid" inside the head. By using this idea he was able to figure out how to locate the eyes symmetrically and how far to "lower" the nose. His procedures for EYES and NOSE included the steps which set the eyes and nose in position, as well as the steps which drew the actual features. They were not state transparent (nor did I suggest that). Each one simply started where the previous one had left off.

Using this mode of "top-down" planning was a big breakthrough for Donald. It meant he could concentrate on one step at a time, and not worry about having to lose or erase the picture of what had gone before. He also had a clear record of where he was at, at every stage of his work. After completing EYES and NOSE, if Donald gave the command HEAD, the computer would draw the head, completed as far as he had gotten, and print the message, "YOU HAVEN'T NOT TOLD ME HOW TO MOUTH AT LEVEL 1 LINE 4 IN HEAD." Etc.

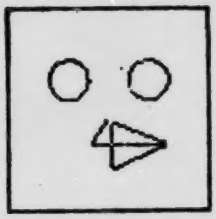


Figure D-9

From this point on, each addition to the head meant a new challenge and new learning to

Donald. To draw the MOUTH, he had to learn about arc procedures. He had to experiment with the size of the arc, to determine the angle at which to orient the turtle before drawing the arc -- and after drawing it. He had to find the point to start drawing the mouth. For Donald these were major challenges and he need at lot of help in analyzing his situations at each point. (classes 11 and 13).

To draw the beard, Donald had a whole new set of problems. I suggested that he make a procedure that would draw one "hair" of the beard, and then repeat this to make a whole beard. I also suggested a plan of making the beard in the following way:

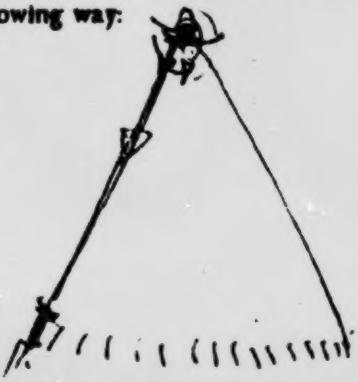


Figure D-10

Donald now had to figure out how long to make each "string" of the beard, how far to turn the turtle before making the first "string", how far to turn the turtle after each "string," and how many "strings" were needed to make a symmetrical beard. After solving all these interrelated problems, he had to figure out where to place the turtle to start drawing the beard, so that it looked the way he wanted it to. (classes 14 and 15)

After making the beard, Donald had a easy time making the hair. He had the turtle draw one "hair", then move over and draw another one continuing until the head was covered. Donald used a REPEAT procedure which I had given him, to make both BEARD and HAIR. He now added the EARS, which was quite simple, and by the end of class 15, had the following:

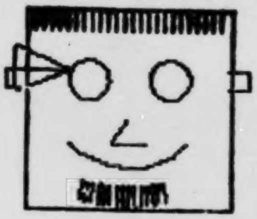


Figure D-11

By this time he had shifted from numbering steps by ones to numbering by tens. When he added a new line to HEAD for EARS, he numbered it line 70:

```
TO HEAD
1 BOX
2 EYES
3 NOSE
4 MOUTH
5 BEARD
6 HAIR
70 EARS
END
```

The next challenge was to locate and draw the hat. He used a variable box procedure (LBOX:SIZE) to draw the top of the hat. He spent part of one period and all of another (classes 16 and 17) figuring out how large to make the hat, and where to locate the turtle to start drawing it. He did this by means of a series of experimental tries, rather than by analysis. He had a hard time realizing that he had to change both items at once to alter the size of the hat and to keep it symmetrically located. As a result, it took him a fairly long time to hit upon a symmetrical solution. Finally he "helped himself" by drawing a diagram of the hat and brim with dimensions marked in, to help him locate the hat properly.

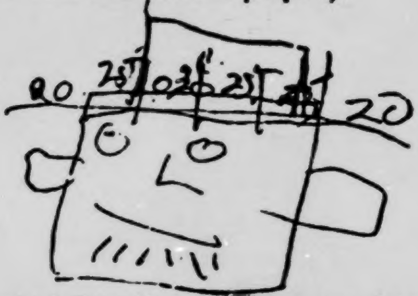


Figure D-12

Class 19 was spent working with a POLY procedure, which Donald wanted to use to draw a "flower" on the hat. Donald and I spent much of the period talking about how the stop rule worked, what "HEADING" meant, and how the computer automatically computed the HEADING by disregarding all multiples of 360 degrees. We added a line PRINT HEADING to the POLY procedure so that we could see how this worked out in practice. Donald had a good understanding of this process and was eventually able to predict exactly when the procedure would stop, by keeping track of the HEADING printed on the screen and figuring out when it was going to equal 360 exactly. Donald finally decided to use POLY 10 100 for his flower.

The final problem, during classes 20 and 21, was to add the flower to the hat. Donald decided to use an arc procedure for the "stem" of the flower. Once again, he had the problem of having to vary both the size and the placement of the stem, to achieve the visual effect he wanted. Donald had a hard time with this, until I reminded him that the RARC procedure he was using had its radius as input, and would extend exactly as high above the hat brim, as the number of units in the radius. He chose a radius of 75 (to make the flower as high as the top of the hat), and only had to locate the starting point for the stem.

One small problem remained -- to locate the turtle so that the POLY procedure would stop correctly. The POLY procedure had a stop rule that only worked if the turtle was oriented vertically before making the POLY. Here are his FLOWER and POLY procedures.

```
TO FLOWER               TO POLY :SIDE :ANGLE
10 RIGHT 90             10 FORWARD :SIDE
20 FORWARD 35           20 RIGHT :ANGLE
30 RIGHT 90             25 IF HEADING = 0 STOP
40 RARC 75              30 POLY :SIDE :ANGLE
50 LEFT 90              END
60 BACK 5
70 POLY 10 100
END
```

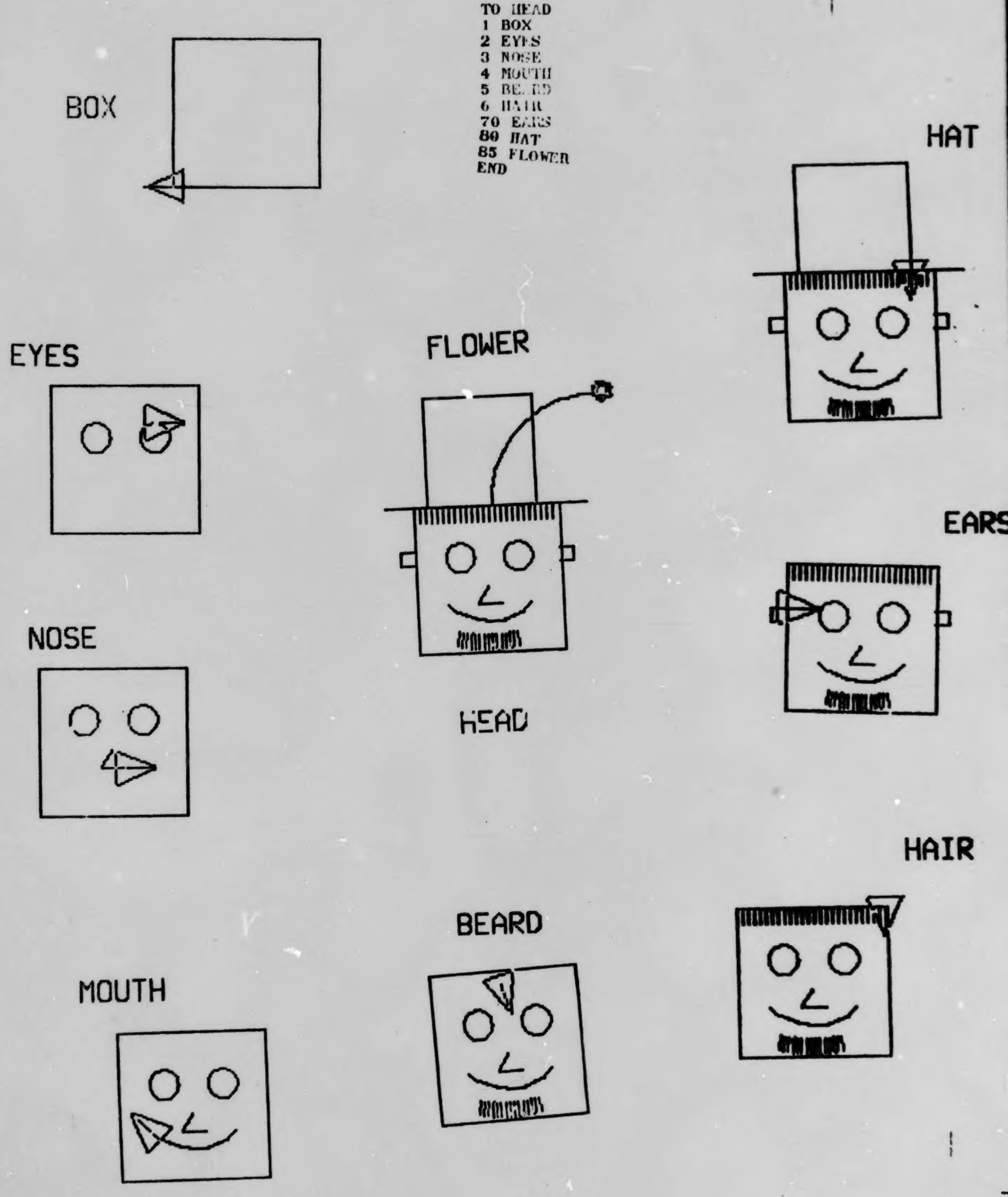
There are some very striking things to be noticed in summarizing Donald's work. His was the longest and most "involved" project undertaken by any of the eight children in the first trial classes. By using the top-down mode of operation, he was able to understand both the overall goal, and where he was in the process at any particular moment. Thus he was able to meet each challenge (and there were many, as we have seen) as just one small problem to be overcome, so that he did not become discouraged about the whole project.

Perhaps the most striking thing about Donald's work was that he was *not* able to solve any of his challenges by experimentation and visual examination of the results. From his first HOUSE procedure, right through the HEAD, all the way to the FLOWER, he made use of *analysis*, combined with experimentation to solve his problems. He often needed help with the analysis, but he always understood what I was showing him, and he was able to make use of it. Scattered throughout his notebooks are little drawings on graph paper, showing the parts he was working on. Some drawings were made by me, some by him, and some by both of us. It is these drawings that tell the story of how Donald accomplished all this, and I present a few of them here, in conclusion.

pictures from notebook follow:

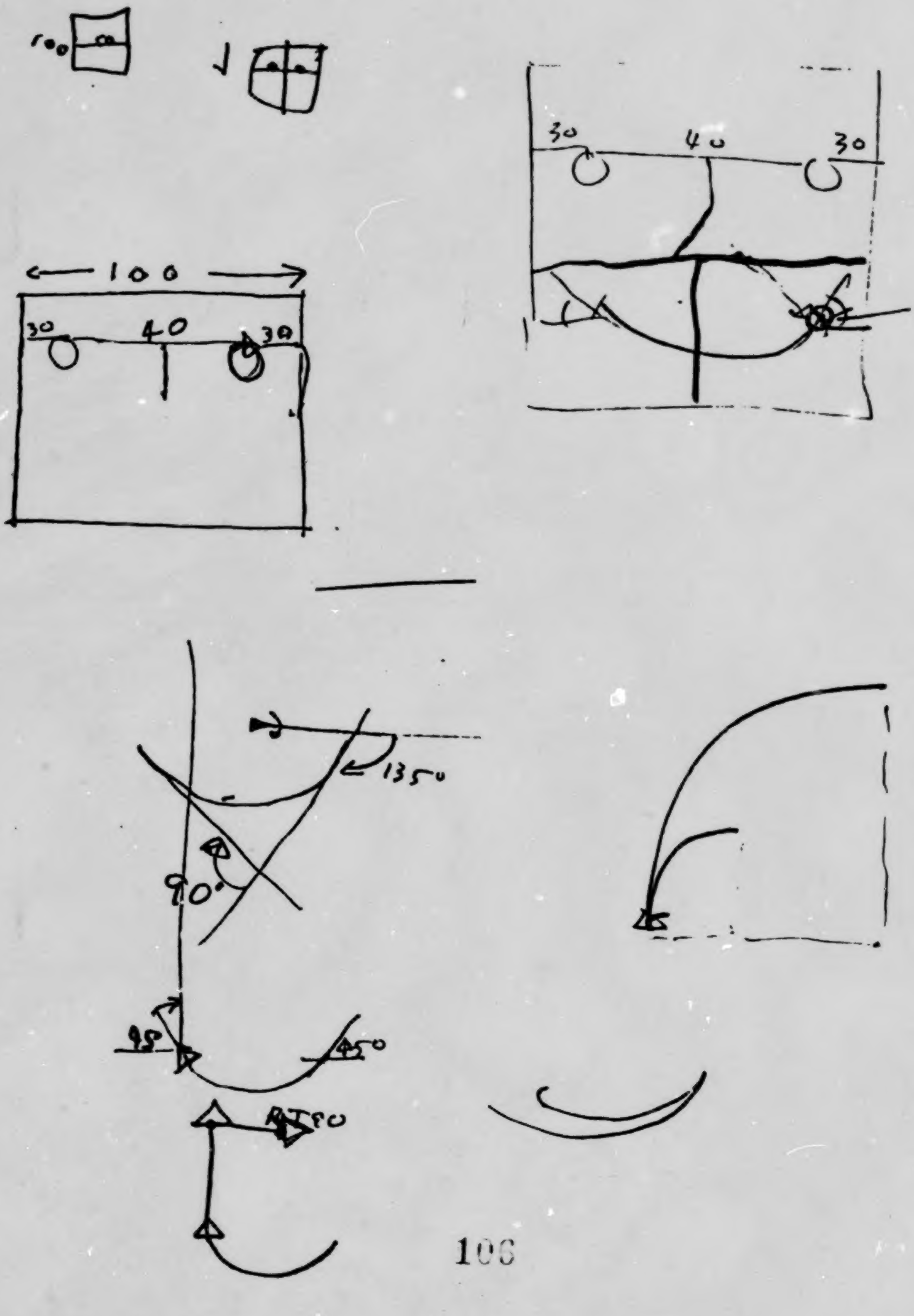
Figure D-13

HOW TO BUILD A HEAD



```
TO HEAD
1  BOX
2  EYES
3  NOSE
4  MOUTH
5  BEARD
6  HAIR
70  EARS
80  HAT
85  FLOWER
END
```

Figure D-14



Individual Profiles -- Laura

Laura got into working with LOGO very quickly. She seemed to master basic ideas of the language: use of turtle commands, syntax for writing procedures, using procedures as subprocedures, naming procedures, etc. She then worked really well for about the first 12 or 13 sessions -- after which her work bogged down a bit as a I introduced several new ideas in close succession, and the projects she was trying to do became harder.

Throughout the 26 sessions, Laura had a tendency to try to learn quickly. She wanted to "know" the answer immediately and preferred not to ask for help except when absolutely stuck. She also did not like to be observed while working. She sometimes had a difficult time articulating her purposes in working. Whether this was due to the fact that she herself did not know her purposes, whether she knew them but could not articulate them, or whether she just felt that they were "private" and did not want to share, is not clear to me. What is clear is that according to the dribble file, there were times when she was clearly confused about left and right turns, about the effects of a series of steps in a procedure, or about error messages generated by misunderstandings about LOGO syntax -- and she did not ask for help, or use any other thoughtful strategies for clarifying her confusion. Laura often evidenced confusion by appearing bored, or by acting in a particularly "perky" manner. As I describe Laura's experience I will try to identify what I believe she learned solidly, and what she evidenced confusion about.

At the very first session, Laura showed great interest in names and in "communicating" with the computer. She noticed "FOO" on the display screen, and asked "Does the computer eat? It says 'FOOD'" She was also very interested when a typing mistake put "BLT" on the screen, and the computer responded "YOU HAVEN'T TOLD ME HOW TO BLT." (Much later she was to say "let's teach it how to BLT," and "Gary, remember BLT?"

During this same first section, Laura had a good deal of difficulty "driving the turtle" -- choosing correct numbers for right, left and forward. She appeared "bored" with turtle driving activities, and I introduced the idea of writing a random procedure, and repeating it -- an idea that Laura seemed to enjoy and understand -- but that she never tried for herself when working alone. At session 5, Laura got her first chance to work alone at a graphics terminal. Laura worked without advance planning. She built an elaborate open ended design, using direct commands quite carefully, to put a rectangle around a circle. At session 6, she did another elaborate design involving many instructions, some of which had already disappeared from the screen before the design was complete. When she attempted to "capture" the design on paper so that she could teach it to the computer, she had already lost some critical steps from the first part of her exploration.

At the beginning of the next session, I suggested that she plan a simple design by drawing it first on paper, then trying it out, and then trying to teach it to the computer. Laura decided to make a face, and drew a simple face on paper. (See Figure L-1-)

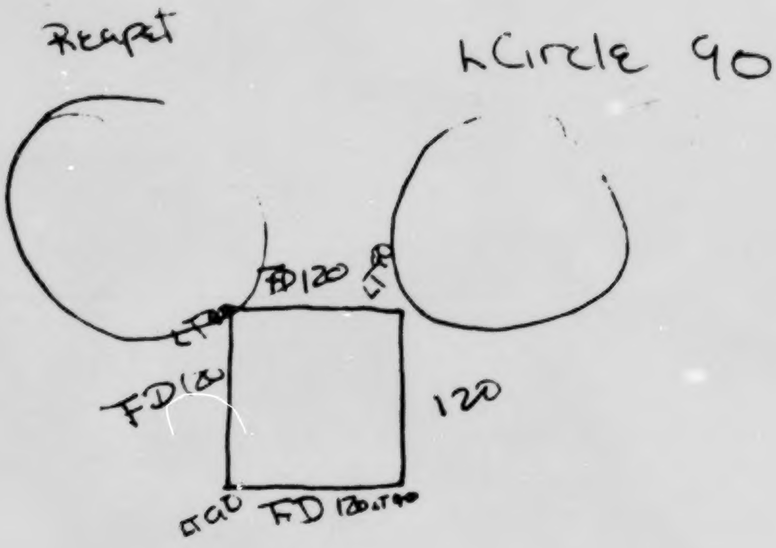


Figure L-1

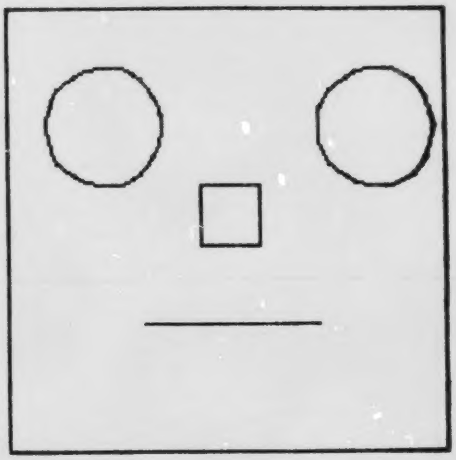
Carrying out this project was difficult for Laura. She had not yet written any procedures, and this project needed sub-procedures. In addition; all her previous designs had been "planned as they went along," with Laura working in "designer mode" -- try this -- then try that. Now she was trying out a fixed plan -- but she did not understand clearly enough how to manipulate the sizes of the elements -- circles and squares, and how to locate the turtle so that they would be in the correct positions. She needed a lot of help from me to work through this project. (See figure L-2)

```
TO FACE
1 NOES
2 RIGHTEYE
3 LEFTEYE
4 MOUTH
5 SQUARE1
END
```

```
TO NOES
1 LEFT 90
2 FORWARD 20
3 RIGHT 90
4 SQUARE
5 RIGHT 90
6 FORWARD 20
7 LEFT 90
END
TO RIGHTEYE
1 PENUP
2 FORWARD 60
3 LEFT 90
4 FORWARD 40
5 RIGHT 90
6 PENDOWN
7 LCIRCLE 30
END
TO LEFTEYE
1 RIGHT 90
2 PENUP
3 FORWARD 80
4 RIGHT 90
5 PENDOWN
6 LCIRCLE 30
END
```

```
TO MOUTH
1 PENUP
2 FORWARD 100
3 RIGHT 90
4 PENDOWN
5 FORWARD 90
6 HIDETURTLE
END
```

```
TO SQUARE1
1
2
3
4
5
6
7
8
10 PENUP
20 FORWARD 70
30 RIGHT 90
40 FORWARD 160
50 PENDOWN
60 LINE1
70 LINE1
80 LINE1
90 LINE1
```

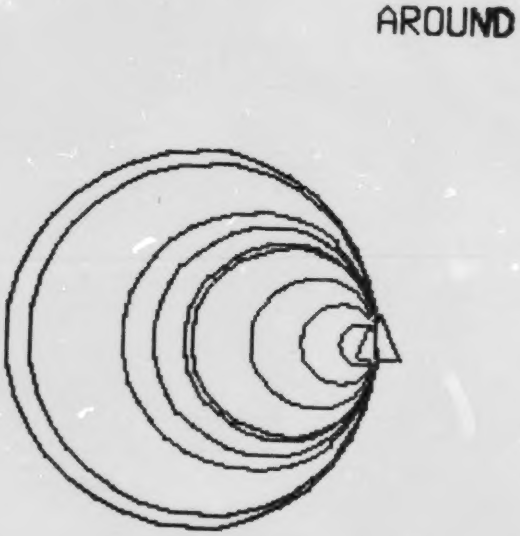


```
TO LINE1
1 RIGHT 90
2 FORWARD 225
END
```

Figure L-2

I now feel that this project was, in a sense an "interuption" of Laura's "natural learning path." The things that she "learned" were not totally absorbed by her at this point. Laura was also put in the position of "needing help", which continued through the next session, until the project was finished. On the other hands, Laura was very pleased with the result, and did have an opportunity to work much more carefully and critically with turtle manipulations. She did write procedures and sub-procedures, and was exposed to the idea of a superprocedure (although she never really used it again on her own!).

In session 9, Laura went back to "designing," this time, using circles of different sizes. It is interesting to note that Laura did not construct her procedure AROUND, a collection of different sized LCIRCLES all starting from the same point, by following a specific pattern -- rather, Laura added the circles in a somewhat random way: Large, smaller, smaller, smaller, smallest, largest, smaller, smaller, larger...as if she were studying the design and asking "what size circle would look good now?" Her procedure was copied directly from the screen to her notebook, and from her notebook to the procedure. She also began numbering steps by 10's. (See figure L-3)



```
TO AROUND
10 LCIRCLE 90
20 LCIRCLE 58
30 LCIRCLE 48
40 LCIRCLE 20
50 LCIRCLE 10
60 LCIRCLE 96
70 LCIRCLE 50
80 LCIRCLE 33
90 LCIRCLE 66
END
```

Figure L-3

I next suggested that she make a symmetrical procedure with RCIRCLEs, and then put them both together. Following this Laura went back to more free form experimentation in her "designer" mode -- try this...then see what looks good next.

Session 11 was one of Laura' best days. She developed a fairly complex -- but not too complex -- design. She copied the steps in her notebook, (with a little help from me), and then taught the procedure to the computer. At my suggestion, Laura made one part of the design a sub-procedure, which simplified the debugging which was later necessary. Laura had to do a lot of debugging -- mostly because she had difficulty copying correctly from her notebook. She worked a lot with the ED and PO command, and I got her to compare the steps as written in her notebook, with the steps as listed in the procedure. She did not debug by tracing through the procedure directly, to see what each step was doing. (See figure L-4)

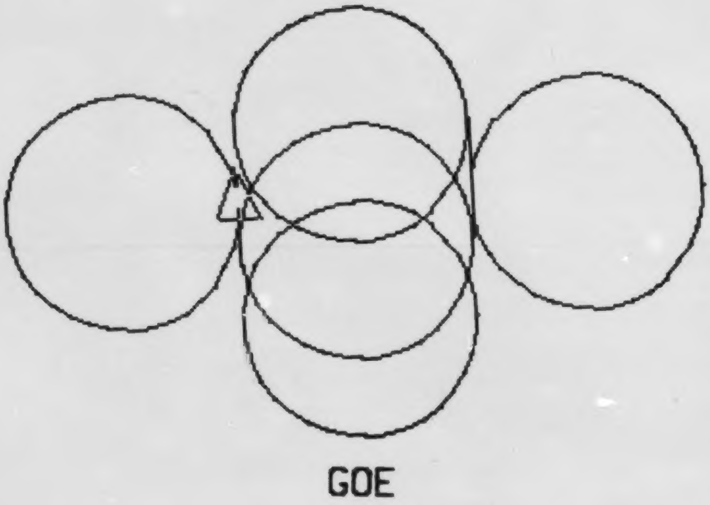


Figure L-4

I have a model of Laura' working style: Try something. If you like it, copy the steps down in your notebook. Then teach it to the computer copying the steps from your notebook. Try to be careful not to make a mistake copying. Although Laura now realizes that procedures can be changed if necessary, she does not see the procedure itself as the thing that you experiment with -- trying it out, and then changing it to make it do what you want. (GEO uses precisely this second method in his work.)

During sessions 12-22, Laura worked a lot with recursion, variables, stop rules, and a long language project -- a "mad lib" game. She did not return to "designer mode" until session 23, when she picked up on one of her first project ideas -- making her initials.

Looking at the dribble files, it is clear that Laura worked on her initials by a proces of trial and error -- then wrote down the correct steps in her notebook. She did not plan ahead or try to think about the easiest way to do it. As a result, she wound up having procedures with many more steps than necessary, as she retraced her course in finishing her letter. Her E, made of just four straight lines, had 15 steps. (The steps were numbered as follows: 10, 20, ...100, 101, 102, ...107.) In addition, she had problems copying steps into and out of her notebook. I suggested stepping through the procedure after printing it out and checking it against her notebook. Laura did not have the idea of stepping through the procedure on her own, (or didn't think she could do it without help, or didn't want to bother doing it without help.)

When Laura worked on her B (her last initial), she ran into exactly the same problems: little or no planning; poor copying to and from notebook; line numbers increase by 1s above 100; confusion about which way to turn the turtle, LT 90 or RT 90; and especially no clear sense of how to debug by stepping through a procedure (playing computer), although I had worked on this technique with her for five classes in a row.

Laura missed two of the last four classes (she was absent for one, and went on a class trip for another) and never completed her initials -- although I believe she would have finished them, and created a superprocedure to draw all three, in about one more session. Laura also did not bring a visitor to class at the next-to-last session, when the children were given an opportunity to do so.

How can we account for Laura' confusion about things that she had worked on so often? I think there are two aspects. From the beginning, Laura had difficulty "driving the turtle," distinguishing between left and right, etc. She is left handed, and often confused left/right. (In her face project, the eye on the right of the drawing was called LEFTEYE which would have been accurate from the perspective of the face -- looking <u>out</u> from the display screen.) She also reversed letters in spelling a lot (NOES for "nose", for example.)

At the same time, Laura demonstrated over and over again, that she did not like to make an <u>analytical</u> effort in her work. She could copy a "formula" successfully, and even have an idea why it worked, but she had difficulty in adapting it to a new situation, or changing it slightly. She rarely made a specific plan that she tried to carry through -- preferring to erase a procedure rather than edit it, and to use CS and start again with a drawing, rather than analyze what was wrong. She even developed a habit of typing POTS, every time she wanted to make any change in what she was doing. This had the effect of displaying a long string of procedure names on the screen, and totally "wiping out" her previous work. (Some kids do the same thing by typing a string of carriage returns.)

I believe that it is important for Laura to "give the world the impression" that she "knows a lot," without making a real intellectual effort to learn. Along with this goes the strategy of hiding what she doesn't know, and when she does ask for help, only attending to the minimal amount necessary to solve the immediate problem -- i.e. get the procedure to do the right thing -- without concentrating on the underlying principles or debugging strategies.

During classes 12-16, I introduced several new ideas to Laura: recursion, procedures with inputs, recursion with fixed inputs and recursion with varying inputs. In classes 17-19 she worked on a long language project - creating a kind of "madlib" game, and then in classes 19-21, she did some more work with variables -- recursive procedures with <u>two</u> inputs.

In session 12 I introduced both recursion, and the use of variables to Laura. I showed her a procedure:

```
TO TWIST
10 LCIRCLE 40
20 RT 30
50 TWIST
```

She then wanted to make TWISTs of different sizes. I showed her how to make the size of the circle a variable. She wrote:

```
TO TWIST2: SIZE
10 LCIRCLE :SIZE
20 RT 90
30 TWIST2:SIZE
```

She seemed to understand what she was doing. Although she had introduced the RT 90 in line 20, she seemed surprised that the shape of her circle design was different. She understood how to vary the size of the design by varying the input to TWIST2.

In the next session (13) Laura continued to write procedures with a variable SIZE. She began to show some confusions. She usually left the :SIZE out of the procedure title. She tried to use EDT, but used it incorrectly and disregarded error messages. She wrote a procedure called TO SQUARE: SIZE, which did not use a variable :SIZE within the procedure. And, when copying from me, the procedure TO SQ:SIZE, she made all the forward steps FD 66:SIZE, not understanding that :SIZE replaced the specific forward step. Once she had the SQ:SIZE procedure defined correctly, she made a very exciting design using SQ 1, SQ 2, ...SQ 82. (See figure L-5)

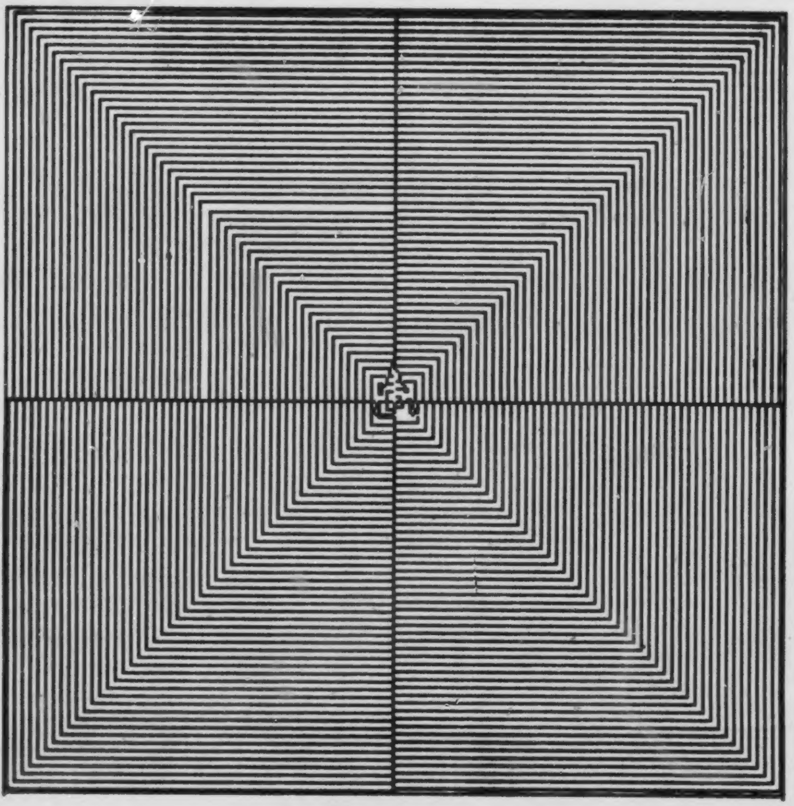


Figure L-5

To capitalize on this discovery, I decided to introduce the following procedure to Laura at the next class (14):

```
TO GROWSQ:SIZE
10 SQ:SIZE
20 GROWSQ:SIZE+1
```

However, when Laura atried to copy this, she typed:

```
TO GROW SQ:SIZE
10 SQ:SIZE
20 GROW SQ:SIZE
```

She forgot to type in the +1, despite a very careful explanation on my part of how the procedure worked. Also, since she left a space between GROW and SQ:SIZE, she kept getting error messages when she tried to use the procedure. She did read the error messages, and tried several ways of typing the procedure, to try to eliminate the error. She tried GROW SQ, GROW SQ 1, GROWSQ 1, GROW SQ 1 100, GROW 1 100, none of which worked. Finally she asked for help, and I suggested she erase the procedure GROW and copy it over, making GROWSQ one word. Notice that she was resourceful in trying different ways of typing the procedure names, but she did not look at the procedure itself to see what was wrong. Another example of Laura' basic working style; lots of trial and error -- no analysis!

Later in the same period, Laura was trying TWIST 80, TWIST 40, TWIST 300. All of these produced the same figure, since TWIST was a fixed instruction procedure. When Laura finally asked for help, I suggested she print out the procedure and look at it -- looking at it together we could see why it always made the same shape. Once again, Laura had tried different things, but had not looked at the procedure to see what was wrong. Still later in the period, she was making a procedure to draw a letter T for a friend, whose name was Tina. She made two attempts TINA, and TINA1, neither of which worked. In neither case did she look at the procedure and try to analyze it.

I began the next session (15) by talking to the whole group about debugging, and the use of PO and step by step analysis of a procedure. Laura spent the period playing around with old procedures, trying to copy other kids procedures from the bulletin board -- without copying the subprocedures needed, and in general wasting time. I interpreted this as "boredom" and decided that I should show Laura a new project. I brought this up with Laura. She agreed to try something new, but in her notebook that day she wrote "By the way, I am not board"(sic). I now feel that she was confused about what had happened when she tried to use variables -- that what she needed was more simple projects using variables in procedures and subprocedures. I had given Laura more ideas than she could absorb in classes 12-14, and this was the message she was giving me -- not boredom.

Instead of giving Laura an opportunity to play around with things she already knew, and to consolidate what she was learning about variables. I launched her into a new project: writing a program to produce Madlibs. This was a learning experience for her. She had to clarify her ideas about nouns, verbs, adjectives and adverbs and how they are used in English -- as well as to make up a simple story, and choose lists of words that would make the story funny. On the other hand, it presented her with a whole new set of things to be confused about, as well as requiring a lot of precise typing. Although Laura was able to understand the language aspects of the procedure, it is unclear what she understood about the programming required, which involved the use of OUTPUT, MAKE and a bit of list processing. Laura was pleased when the project was completed -- but she hadn't been able to do much of the programming or understand how the procedures worked.

If I were continuing with Laura as a student now, I have a few ideas of how I would try to shape her experience to enhance her learning:

1. I would encourage her to continue explorations with turtle commands. She still has a lot to resolve in the areas of left/right discrimination, analyzing sequences of steps to see their effect, and attention to detail in copying.

2. I would try to stress planning of simple projects like initials, encouraging more use of subprocedures.

3. I would go back to simple applications of variables, again with stress on planning -- what is supposed to change? where does it belong in the procedure? what name is chosen for the variable? etc. Then there would be examples of the use of procedures with variables as subprocedures, in both recursive and non-recursive situations. I do think that Laura was close to understanding these points -- but got presented with too much, too soon.

4. One area which Laura did not really get into, which might excxite her as a designer, is repetition of a random set of commands.

5. I would experiment with the use of an automatic drawing procedure like DRAW, so that Laura could experience success with some of her more elaborate designs.

Given Laura' avoidance of "cognitive risk"; her reluctance to reveal her confusions; and her desire to appear to "know" everything instantly, she would always be a difficult child to teach. On the other hand, situations with more stress on ways she could plan and predict outcomes, and fewer sources of confusion introduced from outside, could possibly help Laura assimilate some of the problem solving skills which she is now avoiding.

Individual Profile; Deborah

Deborah is a child who began by being extremely timid and dependent in interactions with the computer. She experienced great difficulties with simple projects, and could not even remember to use the carriage return at the end of a line of instructions, until the 8th class session. Starting at the 8th session, she was encouraged to "experiment" with direct commands, FORWARD, BACK, RIGHT, LEFT, CIRCLE and ARC. She was able to gain confidence when experimenting by limiting herself to very few commands, and to only a few numbers, which she repeated over and over. By focussing on certain numbers, for example 90s and 30s, which make very nice designs, she was able to produce interesting effects, and gradually learned to write procedures, to teach the computer to draw the designs she liked.

By the end of the series of classes she had created some unusual designs which won praise from her classmates, had carried out (with some help) a major project requiring the use of planning and subprocedures, and had a strong confidence in her ability to use the computer. She had invited both of her parents to visit the class, and they remarked to me that this was the first time that Deborah had been excited about anything in school. Deborah's teachers report that she has also become more assertive in class, has asked for extra help after school, etc.

I believe that the key to Deborah's success was her own strategy of limiting her options to a very few choices, gradually expanding the choices as she became comfortable with the familiar ones. During class 8, for example, she limited her explorations almost entirely to FD 30, BK 30, RT 30, LT 30 and RARC 90. Notice how "convenient" the number 30 is for such explorations. RT 30 repeated 3 times makes a right angle. Since RARC 90 makes an arc of radius 90, and Deborah discovered quickly that repeating RARC 90 four times makes a circle, Deborah was able to make designs that had overlapping circles, all of radius 90, separated by multiples of 30. Using this approach, Deborah was able to produce pleasing designs "by accident" without going through some of the struggling that other children do, who use a much greater range of variables, and who engage in a lot more planning than Deborah did.

I use the words "convenient" and "by accident" to describe Deborah's fortuitous choices, because I have no idea why Deborah chose those numbers rather than numbers like 99, or 100, which many children choose for their initial explorations. I can only say that throughout her work Deborah seemed to have a "knack" of making choices that worked out well.

For the first 8 classes, Deborah had been compulsive about getting correct results. She needed absolute assurance on each step, and would not even write in her notebook, without first writing on scrap paper, asking me if it was correct, and then copying it in her notebook. She was a fairly accurate copier, which was a boon to her later work. Deborah worked for most of the first seven classes on a "project" of making the computer draw her initials. Since this design had to be "correct," the "compulsive result getter" in Deborah would not allow her to make a single mistake. So, doubting her own ability, she had to ask for help on every step -- even including when to push the carriage return key.

Once she got into "experimenting" mode, however, the compulsive need for success was eliminated, and Deborah began to feel really successful "without really trying". Deborah brought her copying skills into play, and developed a good way of writing procedures. Once she had a design she liked, she would look at the terminal, to find the last CS command on the screen. Then she would copy into her notebook, all the steps following the CS. If she accidently had a LT 30, followed by a RT 30 to correct it, she copied both, choosing to exercise no judgement as she copied. (By contrast, Laura often exercised judgements in leaving out unnecessary steps when she copied, and often made errors, leading to very perplexing bugs.) I showed her how she could put a title at the top of her list of steps, number each line, put the command END at the bottom, and copy all that, back into the terminal.

Deborah did sometimes make some mistakes in copying. When she did, she had two ways of checking: First she checked that the steps on the screen were copied correctly in her book; second, that the steps in her book were copied correctly in the procedure. A common repeated error was leaving out line numbers when typing the procedure. She could correct this herself, however, by retyping as much of the procedure as necessary. (She always incremented line numbers by ls, until near the end of the classes.) When Deborah made a mistake, she would say "I goofed," in a wistful voice, and ask for help or reassurance. Gradually she came to realize that she had ways of fixing "goofs" by herself, and began to need help less and less. I noticed an interesting use of language. When Deborah was experimenting freely, she would say "I'm just goofing around." I'm sure there's some connection in her mind between the two uses of "goof".

My approach to teaching Deborah was to show her no more than was necessary to help her accomplish her purposes. I showed her ED and PO to help with editing, and very little else for a long time. I wanted her to feel in control, and since she was carefully limiting the choices available to her, I did the same. At one point, when she was trying to repeat a series of steps, I showed her a model of recursion -- which she promptly rejected, and went back to laboriously repeating the sequence of steps. I considered it crucial that she have the opportunity to reject any and all of my suggestions. When I "guided" her into a "simple" project in the early classes, she was paralysed by the need for success, and I was stuck almost literally "holding her hand," in a way that perpetuated her dependence. I continued to make suggestions, which she was free to accept or reject.

Deborah revealed some remarkable strengths in her work. She had the ability to limit her choices, and to experiment comfortably in a self-limited world. She could reject well meaning suggestions as to how to improve her work in favor of ways that she was sure of. She repeated successful activities over and over again until she was really secure with them, and ready to extend her world. She was able to accept suggestions when appropriate for her -- provided that she had control of whether to accept or reject them.

I wonder how often Deborah's working style has been understood as a strength by adults, teachers and parents, who have tried to shape her learning.

I would now like to describe some of her work in more detail. In session 9, Deborah experimented more with repeating angles: RT 30, 9 times, and RT 40, 7 times. Notice that RT 30, repeated 9 times, produces a left turn of 90 degrees. She also used other inputs -- almost all multiples of 10. At one point I noticed she was experimenting with arcs, and increasing the number each time. I suggested she start with a small number, keep increasing it, to make a spiral. She accepted this idea (notice it grew out of her own work), and created a spiral which she liked, and taught to the computer as SPYRO. Her first procedure after completing her initials. (Figure De-l)

```
TO SPYRO
1 RARC 20
2 RARC 20
3 RARC 30
4 RARC 30
5 RARC 40
6 RARC 40
7 RARC 50
8 RARC 50
9 RARC 60
10 RARC 60
11 RARC 70
12 RARC 70
13 RARC 80
14 RARC 80
15 RARC 90
16 RARC 90
17 RARC 100
18 RARC 100
19 RARC 100
20 RARC 10
END
```

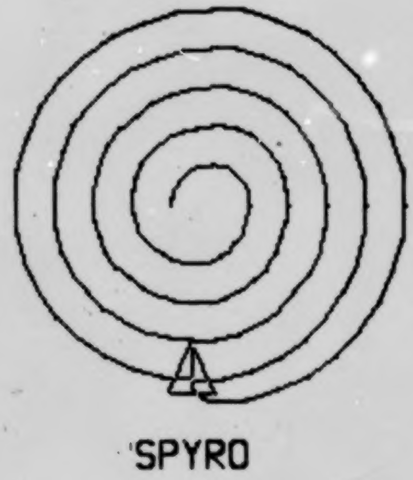


Figure De-l

During session 10, she did some more work with repetition of angles: RT 30, 9 times (270); RT 30, 6 times (180); RT 40 3 times (120); and other combinations: RT 40s and RT 30s, RT 40s and RT 50s. At one point she did RT 40 RT 50 RT 60 Rt 30 (180). At the end of the period she began to use small steps, and small numbers to make a drawing of a "man". She liked the final product, but it had too many steps for her to copy successfully. She didn't even try. At the end of the period, Deborah and Laura showed each other their work. This was the first time this had happened since the beginning of the sessions. Deborah was absent for the next three classes!

Deborah picked up in her work right where she left off. She began by making a design to draw "eyes". (See figure De-2a,) The design was created by repeated RARC 90, four times, followed by four LARC 90s, followed by four RARC 40s and four LARC 40s. When she copied the steps from the screen into her notebook, she copied an extra RARC 40, so that when she copied from her notebook, her procedure had a bug in it, which produced a drawing that had the fourth circle out of place. Deborah looked sad and said "I goofed." I clarified with her that to make a circle required four arcs (she "knew" that), and we stepped through her procedure, and found an extra RARC 40 on line 13. I shoed her how to use ERL 13 to eliminate it from the procedure. Now EYES had the desired result. (See figure De-2b)

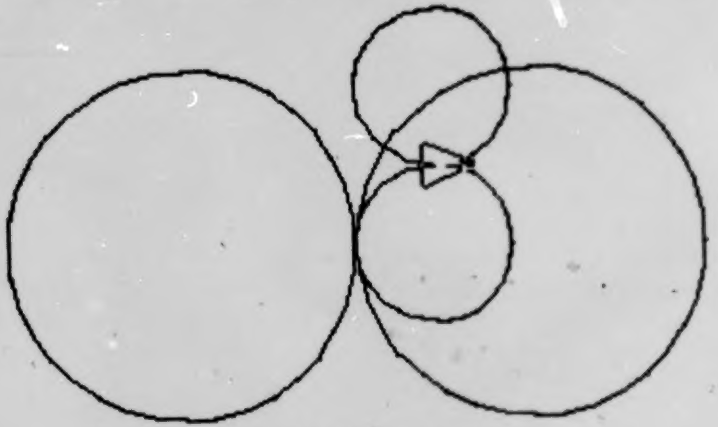


Figure De-2a

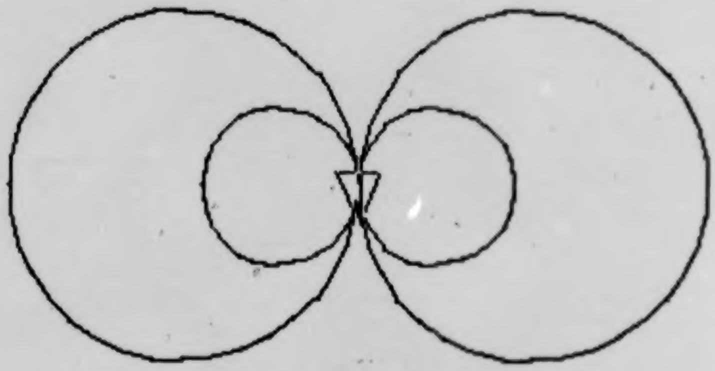


Figure De-2b

The important thing to notice here is that Deborah would not have been able to debug in this way on her own. She might have given up, or, if she had wanted to persevere, I believe she would have cleared the screen and started the whole process again with direct commands, copying the steps, etc. She had not developed a sense of the relation between her procedure, and the list of steps that caused it, as a series of separable independent entities, that could be looked at and analysed one by one.

Later I did suggest that she teach the computer to make a circle -- which she did, by using four RARC 90s. Still later, she made a kind of "cross" using SQUARE -- as a subprocedure . She knew, without any trials, that she had to use RT 90s and FD 30s to make a design using SQUARE. (See figure, De-3).

A kind of "subprocedure" consisting of SQUARE, RT 90, FD 30, was used to make SQUAREs 2, 3, and 4, but Deborah didn't see this. At one point she used RT 90 four times in the middle of the process. For her, each of those four steps was as important to the product as any other steps.

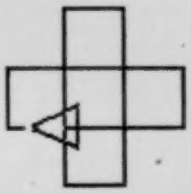


Figure De-3

In session 15 I suggest she work with her CIRCLE procedure, and try CIRCLE, RT, CIRCLE RT, ... to make a design. She tried this and chose to turn right 60 after each circle, calling the resulting design FLOWER. (Another one of her serendipitous choices? She had not used the command RT 60 since class 10.) (See figure, De-4)

I also tried to show her how to write this procedure recursively, but she wouldn't try it.

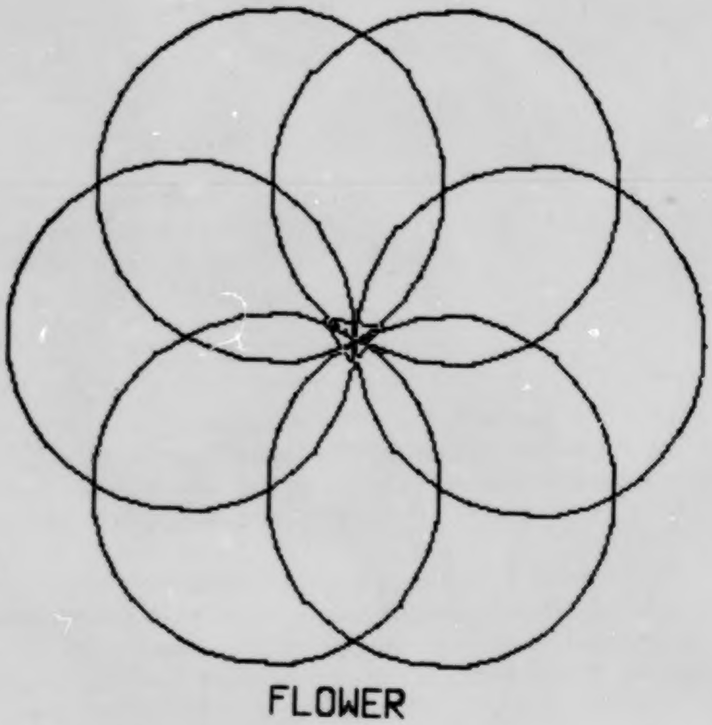


Figure De-4

In session 16 she began to develop a project idea. She made a drawing of a rabbit (See figure De-5a), but then said, "It's too hard." I suggested a modification, using a square head, and triangular ears, that I thought might be easier, although I thought that it would be difficult for her as well. (See figure De-5b)

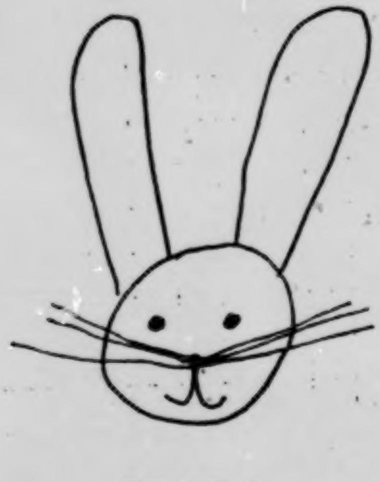


Figure De-5a

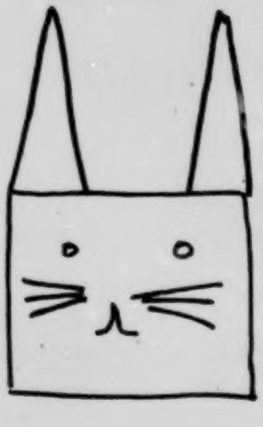


Figure De-5b

In session 17 Deborah began working on the rabbit (square version). She got as far as building a square using FD 70, FD 60, to make a side of length 130. She repeated FD 70, FD 60, all around the square. She then moved up the side of the square to make the eyes. Then she got confused, cleared the screen and tried again. When she hit a snag again, she cleared screen again, and went on to another project -- rotating her FLOWER design and repeating it.

In session 18, Deborah watched a film which showed a number of computer designs. Among the designs shown was a six pointed star. Deborah came right back from the film, to class, and drew a six pointed star with the computer, without making a single mistake. She began by turning the turtle RT 30, and proceeded to draw the star by using a combination of FD 70s, and RT 60s. Again, her choice of RT 30 for the first step, and RT 60 for the turns is absolutely correct. Her strategy was to move the turtle forward 70, and then repeat RT 60 until the turtle was aimed in the right direction. The totals needed are RT 120 at the points, and LT 60 at the inner vertices. Deborah achieves the LT 60 by repeating RT 60 5 times. I don't believe that Deborah realized that she was always repeating RT 60 two times and five times. At each point, she just kept turning the turtle until it was pointed in the right direction. At one point, Deborah missed the correct direction, and continued repeating RT 60 for a total of 11 times until the correct orientation was achieved.

```
TO STAR
1 RIGHT 30
2 TRYANGLE
3 LEFT 60
4 TRYANGLE
5 LEFT 60
6 TRYANGLE
7 LEFT 60
8 TRYANGLE
9 LEFT 60
10 TRYANGLE
11 LEFT 60
12 TRYANGLE
END
```

```
TO TRYANGLE
2 FORWARD 70
3 RIGHT 60
4 RIGHT 60
5 FORWARD 70
END
```

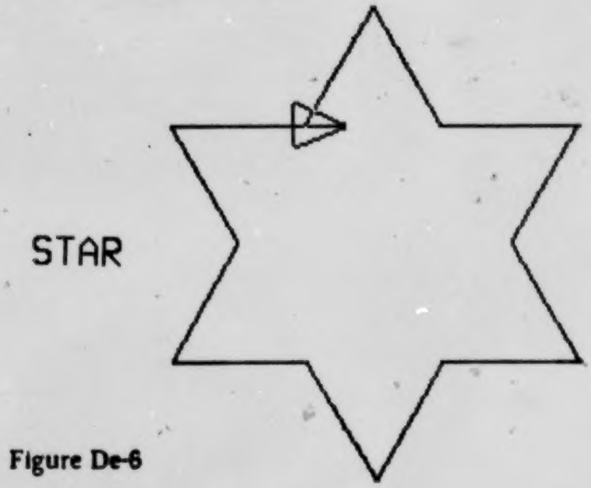


Figure De-6

I decided to suggest that I knew an "easier" way for Deborah to teach the computer how to make the star, than to copy all the steps (I had noticed at least one error in the steps copied into Deborah's notebook.) I suggested that Deborah teach the computer how to make <u>one point</u>, and then repeat that to make the star. Deborah accepted the suggestion, and taught the computer:

```
TO TRYANGLE
1 RT 30
2 FD 70
3 RT 60
4 RT 60
5 FD 70
END
```

Since TRYANGLE included the first step, RT 30, it could not be used as a subprocedure, which Dianne noticed when she tried to use it. I removed the extra step for her, and reminded her she had to have the step RT 30 first.

After Deborah had drawn the first TRYANGLE correctly, I asked her what command she had to give the turtle next. She looked at the situation carefully and after some time, said, LT 60! We tried it and it worked. After that, she was able to build the star by repeating TRYANGIE, LT 60, for a total of 6 points. Deborah's procedure, STAR, copied from screen to notebook and from notebook to screen, consisted of RT 30, followed by 6 repeats of TRYANGLE, LT 60. (See figure De-6)

In session 19, Deborah came back to the Rabbit again. This time, she chose FD 90, FD 30 as the commands to make each side. After several tries, to make the eyes and the nose, I suggested breaking the problem into parts, and teaching each part to the computer separately. Deborah agreed to this, and we decided that the should teach the outside of the rabbit first. She could not think of a name for this, and finally decided to call it HAT (?). In copying she made a mistake and left out a step, which I had to help her debug. (See figure De-7a)

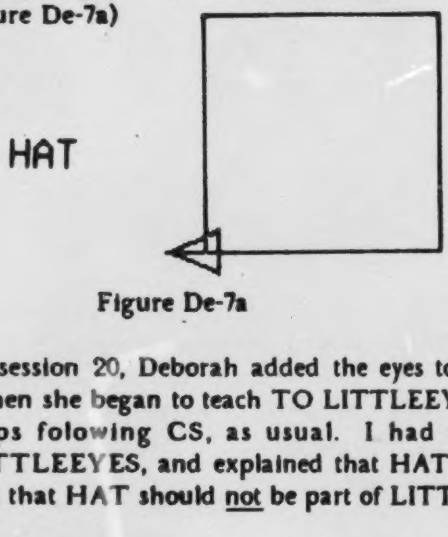


Figure De-7a

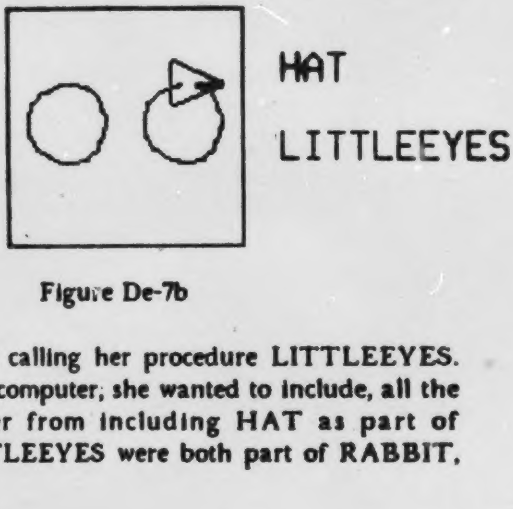


Figure De-7b

In session 20, Deborah added the eyes to the head, calling her procedure LITTLEEYES. When she began to teach TO LITTLEEYES to the computer, she wanted to include, all the steps folowing CS, as usual. I had to stop her from including HAT as part of LITTLEEYES, and explained that HAT and LITTLEEYES were both part of RABBIT, but that HAT should <u>not</u> be part of LITTLEEYES.

Her "luck" held in choice of distances for placing the eyes. Since the sides of the head were now 120 units long, and since she moved the turtle across the head in units of 30, she was able to center the eyes with no difficulty. (See figure, De-7b)

In class 22, Deborah began to work on the nose, and got really stuck. She had two different things she was trying to resolve. How to make the nose, and where to put it. I suggested that she separate the two parts, and make the nose all by itself -- forgetting about the rest of the rabbit for the time being. Then, once a good nose had been made, she could work on placing the nose in the right position.

Deborah planned to make the nose as shown in figure 5. I showed her how to do this by starting with RARC, turning the turtle all the way around, coming back to the beginning using LARC, and then reversing the whole thing to make the other side. Deborah understood the idea, but needed help working it out. To turn the turtle around, Deborah tried RT 90, then tried RT 90 again (at least it wasn't six RT 30s). Whenever she needed to turn the turtle around she used RT 90, RT 90. (See figure, De-7c)

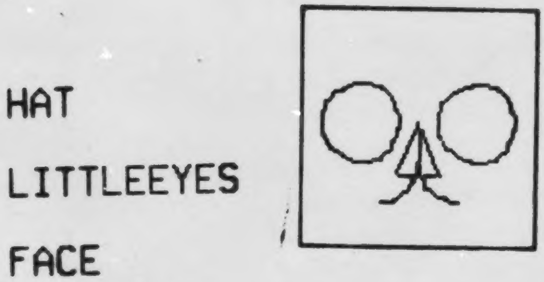


Figure De-7c

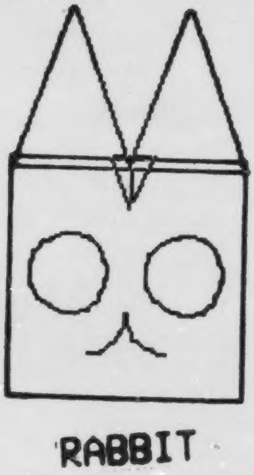


Figure De-7d

Later, when she began to make her ear, she again demonstrated her uncanny accuracy in choice of inputs. She had moved the turtle to the top of the rabbit's head. Her steps to make the first ear were: RT 20, FD 90, RT 90, RT 30, RT 20, FD 70, FD 20, RT 90, RT 20. This leaves the turtle facing back along the top of the head, having turned through a total of 270 degrees. Deborah achieved this ear in three tries. The key decision was how far to turn at the top. Having turned Rt 20 at the base of the ear, a turn of RT 140 was needed to make an isoceles triangle. In Deborah's first try, she turned RT 90 four times, then RT 90, RT 30, Rt 30, for a total of 150 degrees. She then had a hard time lining up the far end of the ear with the top of the head. Her second try was RT 900 (mistake), followed by two Rt 90s, to straighten it all out again, followed by Rt 20, RT 20, RT 20, for a total of 150 degrees again. Once again, she had trouble lining up the far end. On the third try, she turned RT

90, RT 30, RT 20, which made exactly 140, which made it easy to line up the far end of the ear, which happens to come out almost exactly at the far end of the head. At this point, Deborah wrote out all the steps, and said "I can do the same thing on the other side. Should I give this a name?"

At the next session (23), I helped Deborah separate the steps that made the ear, from the steps that set it in position. In this way, she could use the same subprocedure, which she called EARS, to make ears on both sides. Her final scheme for completing the RABBIT is shown in figure De-7d and figure De-8.

It was in class 23, that Deborah rejected help from me indignantly at one point, asserting loudly "I know what I'm doing!" In class 24, she completed the RABBIT procedure.

I'd like to try to list the things I believe Deborah learned during the RABBIT project. This includes both ideas that she mastered, as well as ideas that she encountered and used, but hadn't yet mastered.

> --first and foremost -- the idea of using subprocedures; that a large project can be broken down into a group of small projects.
>
> --that using subprocedures can have two parts, drawing the object (nose, ear) and locating it, and that the same subprocedure (ear) can be used in more than one place.
>
> --that a superprocedure can be made to combine all the subprocedures, and that the superprocedure can be a kind of "plan" for doing the whole project.
>
> --that with patience, even complicated problems can be worked out by step by step, trial and error (location of nose, location and shape of ears)_
>
> --that 90, 30 and 20 are really good numbers to use in combinations (In her entire RABBIT procedure Deborah used a total of 75 procedural steps, most of them forwards, rights and arcs. She used the following inputs: 90 (22 times); 20 (19 times -- 14 for arcs); 30 (8 times); 70 (3 times); 3 (3 times); and 60, 50, and 12 1 time each.
>
> --for the first time, she developed complete confidence in her ability to understand what she was doing: "I know what I'm doing!", despite frequent "goofs". Perhaps this was really the most important learning for Deborah -- not just to be in control of a learning environment, but to know she was in control, to feel a sense of mastery.

In the next session, 25, Deborah worked on making a rotated square. It seems apparent from

Figure De-8

```
TO RABBIT
5 HAT
10 LITTLEEYES
15 FACE
20 PENUP
25 FORWARD 70
30 FORWARD 3
35 RIGHT 20
40 PENDOWN
45 EARS
50 RIGHT 90
55 FORWARD 50
60 FORWARD 3
65 FORWARD 60
70 FORWARD 5
75 FORWARD 3
80 RIGHT 90
85 RIGHT 20
90 EARS
END
TO HAT
1 FORWARD 90
2 FORWARD 30
3 RIGHT 90
4 FORWARD 90
5 FORWARD 30
6 RIGHT 90
7 FORWARD 90
8 FORWARD 30
9 RIGHT 90
10 FORWARD 90
11 FORWARD 30
END
TO LITTLEEYES
1 RIGHT 90
2 FORWARD 70
3 FORWARD 12
4 RIGHT 90
5 PENUP
6 FORWARD 30
7 PENDOWN
8 RARC 20
9 RARC 20
10 RARC 20
11 RARC 20
12 PENUP
13 FORWARD 30
14 FORWARD 30
15 PENDOWN
16 RARC 20
17 RARC 20
18 RARC 20
19 RARC 20
END
```

```
TO FACE
1 RARC 20
2 RARC 20
3 PENUP
4 FORWARD 20
5 FORWARD 10
6 RIGHT 90
7 RIGHT 90
8 RIGHT 90
9 PENDOWN
10 NOSE
END
TO NOSE
1 RARC 20
2 RIGHT 90
3 RIGHT 90
4 LARC 20
5 RIGHT 90
6 RIGHT 90
7 LARC 20
8 RIGHT 90
9 RIGHT 90
10 RARC 20
END
TO EARS
1 FORWARD 90
2 RIGHT 90
3 RIGHT 30
4 RIGHT 20
5 FORWARD 70
6 FORWARD 20
7 RIGHT 20
END
```

her comments, that a "square", rotated, is no longer a "square", but rather a "diamond". When Deborah taught DIAMOND to the computer, she included RT 40, and then a series of steps to make a square. Clearly the RT 40 was part of the diamond, rather than "the amount you turn the turtle before making the diamond."

Later I showed her how to make this procedure repeat by using GO, and she made another repeating design with her SQUARE procedure and a turn of RT 4, using GO. Thus, having finished the RABBIT -- a project that lasted for two weeks, with some time out for other work -- Deborah was ready to learn something new

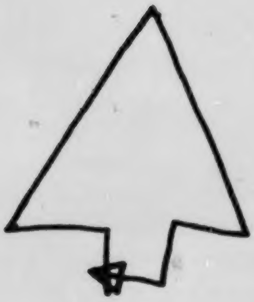
Individual Profiles; Monica

Monica started off in LOGO with a burst of enthusiasm and confidence. She had a very good sense of turtle state, right from the beginning -- an intuitive sense of where a figure would be drawn, a good sense of how far to turn. She was fascinated by the process of making a figure, rotating it, and repeating the process over and over. She easily adopted the use of simple recursion to do this, and created many different simple projects of this type.

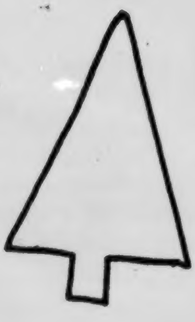
As the classes went on, Monica limited most of her work to this particular mode, and had a hard time getting beyond it. Almost all her work was in the style of "figure, turn, figure, turn.." She learned to use variables, to make the figure turn different amounts, and had some exposure to stop rules, which she didn't quite master. What Monica did not do was get into long term projects of any kind, or show much initiative in breaking out of the "mold" in which she had placed herself.

Monica had a very close relationship with Kathy, the other girl in her class. (According to their teacher, they do not have a close relationship outside of the LOGO classroom.) The two girls often consulted together, borrowed ideas, worked on the same, or similar projects, and asked for and offered help to each other throughout the classes. Their relationship was normally quite "mutual" with a lot of give and take, although leadership shifted back and forth. On different occasions, observers who came for a one shot visit observed: "teacher-student relation between Monica and Kathy. Monica tells Kathy what to do and Kathy always goes to Monica to make sure she has done it right..." or, another time: "Monica was at a loss as to what to do with herself... at last Kathy arrived. Kathy found a worksheet for her...(she) got upset, panicked and ran to Kathy for a new thing to do." Another observer: "K and M work together very constructively -- each on top of things, making suggestions". This last observation corresponds most closely to my sense of their overall relationship throughout. (See notes on Kathy -- pages 3 and 4).

As the classes went on, Monica tended to have fewer ideas of what she wanted to do. She would borrow ideas from Kathy, from the bulletin board, or from a booklet of projects, often copying carelessly, by rote, not thinking about what the steps were supposed to do. Monica did not have much of an inclination to plan, to think ahead, or to debug her work. If something didn't work out the way she wanted it to, she would often just forget about it, leaving a bunch of useless procedures in her file, along with the good ones. Usually she did not ask for help. Although she had been shown how to use ED to change procedures at an early point, she rarely chose to use it, until late in the series of classes. Her procedures tended to be short and simple. If they didn't do what she wanted, she'd forget them. During the last few classes, Monica expressed an interest in debugging a rather lengthy procedure, her HAT procedure, that drew a Christmas tree, so that the stump would be "straight". She wanted to change it from:



TO:



This was her first real interest in any procedures longer than a few lines that did not simply repeat a few fixed steps.

I spent about 20 minutes working with her on it, using STEP to isolate the lines that needed changing. The following class was "visitors day", and Monica never got back to finish the project.

Monica's use of names was erratic. Her "HAT" made a "Christmastree." BOX, TRI, BUS, BUSWHEEL, BUSWHEEL2, HOUSE, HOUSE4, related to specific objects; HORSE, WOW, WISHWOW, BOODLE, HOTHOUSE, were fairly random. She seemed to have difficulty choosing names, as she had difficulty chosing projects.

Monica kept thorough notes of her work by writing down every procedure in her notebook, either before or after trying it out.

During the first few classes, when the group of four children worked together, Monica demonstrated a good understanding of turtle state. By considering where the turtle was, she was able to predict where the next procedure would occur. This was especially useful, because the projects that the children were doing involved making designs with squares, using a BOX procedure. In the sixth class, Monica and Kathy worked together, putting a BOX and a TRIANGLE together to make a HOUSE. Monica had a very strong sense (much better than Kathy's) of how much to turn the turtle, to get the two figures to line up.

On the other hand, when Monica tried to make a triangle, she had great difficulty separating the different variables. She worked steadily for an hour, trying to make a triangle that would close. Her problem was, that she worked without an effective system. She had to deal with five different variables (three lengths and two angles). She had a hard time fixing on which one to vary, and so, kept getting close to a solution, only to have her next attempt produce something quite different. She used two different strategies as she worked, and kept switching between them. She got quite confused about what was happening, and never succeeded in getting the triangle to close. I was very impressed with how doggedly she stuck to the task and how close she came to a solution without actually getting one.

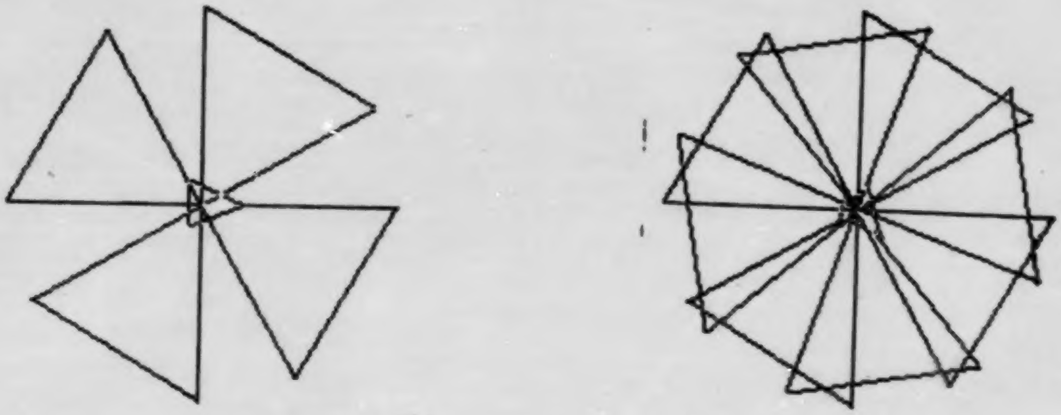
In the seventh class, Monica copied a triangle procedure which was state transparent, (FD

100, RT 120, repeated 3 times), and began to experiment with the effects of putting rotations in between triangles. She put a whole series of triangles rotated at different angles, on top of each other.

Next time, I suggested that she give a name to a definite series of rotations. I suggested that she could call TRI90 a series of repeats of TRI, LT 90; or TRI40 a series of repeats of TRI, LT 40 (both sequences she had used in the previous class). Monica understood my idea about making each design a separate procedure, but her approach was a bit different. She defined three new procedures:

```
TO TRI4                      TO TRI42                     TO TRI442
1 TRI                        1 LEFT 40                    1 TRI4
2 LEFT 90                    2 TRI4                       2 TRI42
3 TRI                        END                          END
4 LEFT 90
5 TRI
6 LEFT 90
7 TRI
END
```

These made the designs shown (figure M-1). Notice that TRI42 was not used by itself, but only with TRI4, as part of TRI442.



TRI4

TRI442

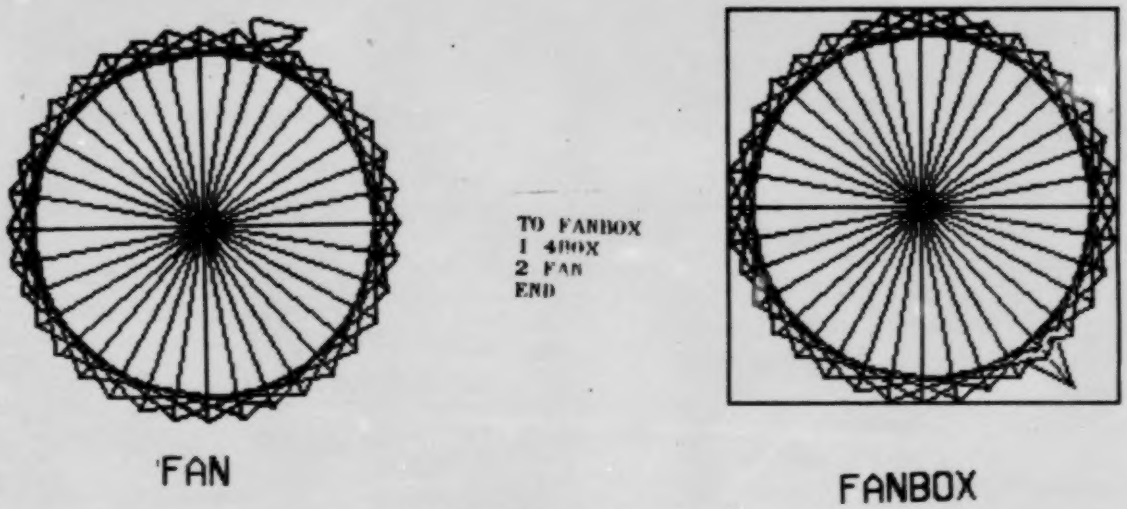
Figure M-1

Most of the rest of the period, was devoted to a lengthy series of repeats of TRI, LT 10.

Monica's plan was to complete a circle of these with this shape, and then to teach it to the computer as a procedure. After 13 repeats, a half circle was completed, and Monica concluded that 26 repeats would produce a full circle. At this point, I introduced recursion to Monica, as an "easier" way to accomplish what she wanted to do. She understood the idea, and used it to make:

```
TO FAN
1 TRI
2 LT 10
3 FAN
END
```

and FANBOX, which combined a procedure made from four BOX procedures, with FAN, to make FANBOX. (figure M-2). I also showed her how to add a stop rule to her FAN procedure, but here she did not understand, and made no attempt to use a stop rule at this point.



```
TO FANBOX
1 4BOX
2 FAN
END
```

FAN

FANBOX

Figure M-2

Late in the period Monica copied another child's procedure from the bulletin board. Because she miscopied the title, (It should have been FOO2, instead of FOO). Her FOO has no graphic effect, but produced a "NO STORAGE LEFT." error message.

```
TO FOO
10 FOO
20 FOO
30 FOO
40 FOO
50 FOO
60 FOO
70 FOO
80 FOO
90 FOO
100 FOO
110
120 FOO
130 FOO
END
```

This was a departure for Monica. Usually she had tried each step of a procedure, then taught it to the computer. Here she copied a procedure verbatim, without realizing that she also needed the subprocedure, FOO, and without checking to see that FOO itself worked. At this point she did not ask for help, or try to debug FOO in any way, but went back to previous explorations.

In classes 9 and 10, Monica continued to work in ways which were becoming a definite pattern: she did more work along the line of THING, rotation, THING; she also did not debug procedures with errors, and ignored procedures which did not do what she wanted. During class 10, she copied some more procedures from the bulletin board, and from a project book. Most of these procedures did not work, either because of errors in copying (like to mistake she had made with FOO) or because she did not pay attention to the subprocedures needed in each case.

Monica recorded some of her difficulties in her notebook, without any attempt to analyze them: "Today I made a DOODLE... and I tried two DOODLES but it wouldn't work out too well.and I tried to make a slinky."

```
TO DOODLE
10 DOODLE
20 DOODLE
30 DOODLE
40 DOODLE
END
```

```
TO SLINKY
10 CIRCLE
20 FORWARD 10
30 SLINKY
END
```

In going over the dribble files for these classes, I realized that Monica was not looking carefully at what she was doing; that she was not editing or debugging; that she was following certain patterns blindly without thinking about them; and that she had run out of ideas for projects. I decided that for the next class I would prepare a list of buggy procedures, discuss each procedure with Monica (and Kathy, who was having similar problems), and then have them try out the procedures to see what the computer would easily do in each case. I had two major aims in doing this: first, to get the girls to notice and focus on the messages sent by the computer in buggy situations. Second, to get them to understand some of the particular kinds of bugs that they were experiencing.

Following this lesson, I noticed that Monica *was* doing some debugging, but that she was still having difficulty understanding how to use the EDIT command (she was following the ED command by a line number, rather than a procedure name). We worked through one problem together, using PO, ED, and analyzing the procedure step by step. In this way, I hoped to give Monica a model of how she could work in other situations without help.

In class 13, I introduced both Kathy and Monica to the idea of variables, by giving them a variable square procedure, SQ:SIZE. I had also made up a little sheet of possible project ideas. Monica and Kathy both chose to make a bus (figure M-3).

Monica worked on the bus for parts of two periods. Once again, she had problems editing, editing the *line*, rather than the procedure. For example, her buswheel procedure was

```
TO BUSWHEEL
1 BUS
2 LT 90
3 RCIRCLE
END
```

When she ran BUSWHEEL, she got the error message; "RCIRCLE NEEDS MORE MORE INPUTS AT LEVEL 1 LINE 3 IN BUSWHEEL." Her response was to type ED RCIRCLE. Clearly she *was* reading and interpreting the error message, and using the information to try to debug her work, but she did not understand the proper use of EDIT.

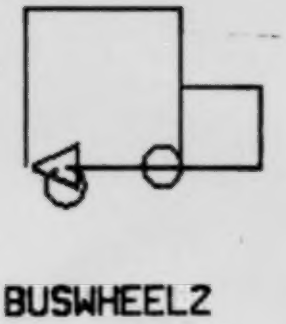
Another bug surprised me. She had a problem with the turtle state, in aligning the wheels properly. Her debugged procedure was:

```
TO BUSWHEEL
1 BUS
2 LT 90
3 RCIRCLE 10
END
```

when used to make a complete bus:

```
TO BUSWHEEL
1 BUSWHEEL
2 RT 90
3 FD 60
4 RCIRCLE 10
END
```

makes a bus with a bug, shown in figure M-3.



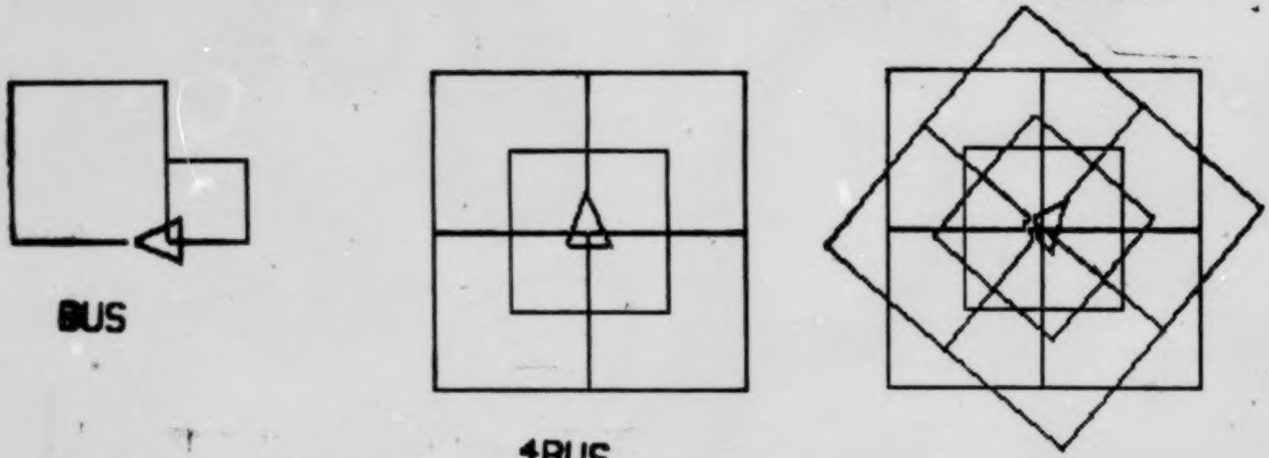
```
TO BUSWHEEL2
1 BUSWHEEL
2 RIGHT 90
3 FORWARD 60
4 LCIRCLE 10
END

TO BUSWHEEL
1 BUS
2 LEFT 90
3 RCIRCLE 10
END


TO BUS
1 SQ 40
2 LEFT 90
3 SQ 80
END
```

Figure M-3

Either Monica did not notice that the wheels were at different levels, didn't feel it was a problem or didn't want to bother with it. She ignored it deciding that the project was completed. She went on to other work, going back to her old pattern of procedure, rotation, procedure, to produce some more nice designs (see, for example, figure M-4 for a way that Monica used her BUS procedure in a more familiar mode.)



BUS

4BUS

'STAR

```
TO BUS
1 SQ 40
2 LEFT 90
3 SQ 80
END
```

```
TO 4BUS
1 BUS
2 BUS
3 BUS
4 BUS
END
```

```
TO STAR
1 4BUS
2 RIGHT 40
3 4BUS
END
```

Figure M-4

In the next three classes (15, 16, and 17) she continued to use the rotation idea, sometimes with recursion, to make procedures like:

```
TO DESIGN              TO DOG
1 STAR                 1 BOX
2 RIGHT 40             2 RT 70
3 DESIGN               3 DOG
END                    END
```

Her projects were short, and she did not have to edit. She did borrow one long procedure -- Kathy's XMASTREE, which Monica decided to call HAT. In using this procedure she did have to edit, and asked me to help with the EDIT command.

Although Monica had been using rotations to produce designs, it was very obvious, that she had not developed any particular sense of the effect of using particular angles. She had used rotations of 10, 20, 40, and occasionally 70 or 90 degrees in her designs. Although she did seem to prefer "dense" designs, she seemed to have no way of predicting the effect of using a particular angle, or the sense that certain "special" angles might produce nice designs that "closed" in a predictable way.

I decided to suggest that Monica write some new procedures that used a variable angle, so that she could experiment with the effect of changing the angle. I showed Monica a couple of models like:

```
TO SPINBUS : ANGLE
10 BUS
20 RT :ANGLE
30 IF HEADING = 0 STOP
40 SPINBUS :ANGLE
END
```

The use of the stop rule, was another suggestion of mine, to help Monica focus on when the design was "complete" Monica used this model to define procedures that would rotate her HAT procedure, her WOW procedure (a series of nested squares) and her HOUSE procedure.

In typing these procedures, Monica had some difficulties with syntax. She usually left out the :ANGLE in the procedures title. I showed her how to use EDT. Now she was using ED properly, but still had difficulty with EDT. She did, however, correctly interpret the error messages, and debug the procedures on her own.

In class 21, I asked Monica to choose one of her procedures, and experiment with varying the input, keeping records of the results. She chose to use the procedure

```
WISHWOW :ANGLE
```

which rotates a bunch of nested squares. (figure M-5)

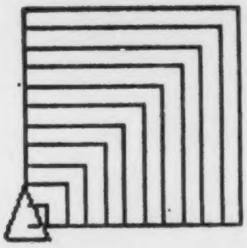
She kept meticulous notes in her notebook, describing what the shapes looked like, how they grew, and comparing them with similar shapes. For example:

> "WISHWOW 160 looked the same as WISHWOW 40. It had thin cones and there were 9 of them.
>
> WISHWOW 165 had thin webbed cones and you couldn't really see them that good.
>
> WISHWOW 190 had cones but they looked like they didn't close up. And it was fatter than other ones. It had more squares and cones. The cones were thin. And close together.
>
> WISHWOW 45, WISHWOW 90. These 2 look almost the same but WISHWOW 45 looks like it goes twice around instead of once. And the cone shaped things on the sides are bigger than the WISHWOW 90 ones."

Class 21 turned out to be the last time Monica actually worked on a project. Clearly, she was

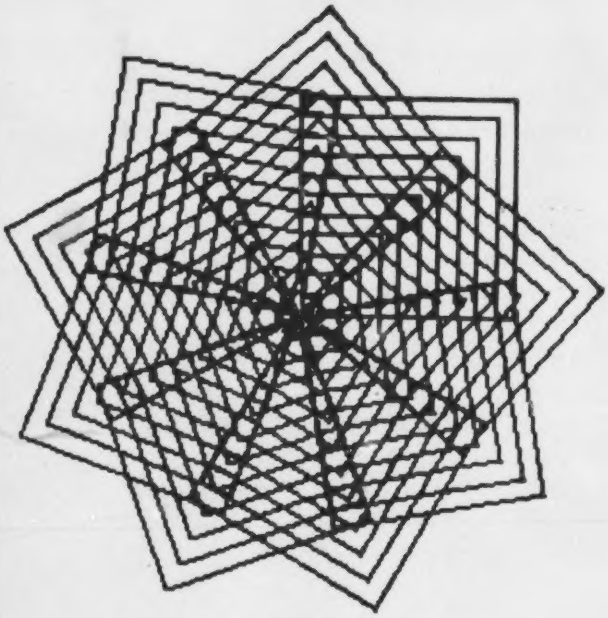
Figure M-5

```
TO WOW
1 SQ 10
2 SQ 20
3 SQ 30
4 SQ 40
5 SQ 50
6 SQ 60
7 SQ 70
8 SQ 80
9 SQ 90
10 SQ 100
11 SQ 110
END
```

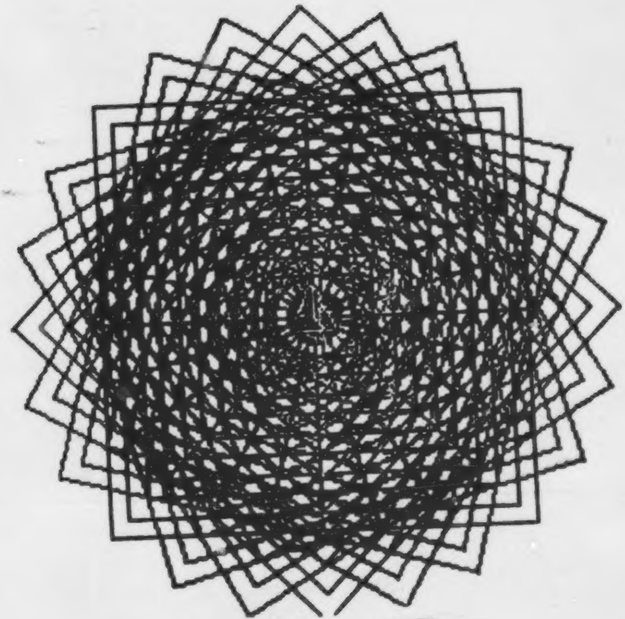


WOW

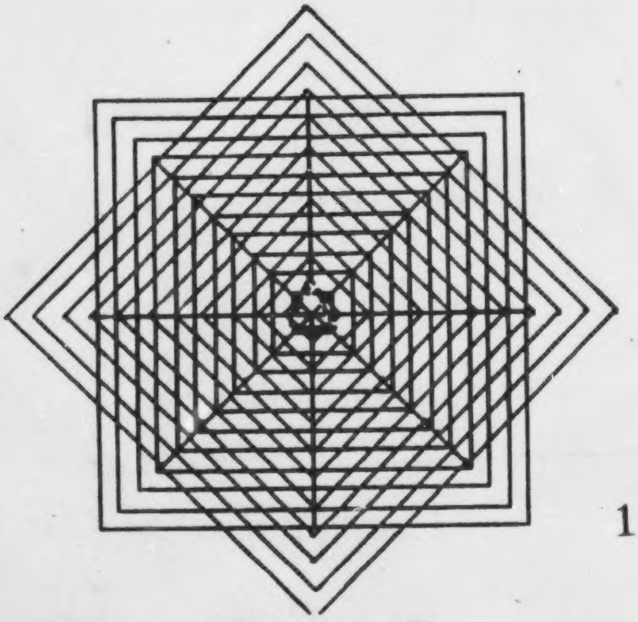
```
TO WISHWOW :ANGLE
10 WOW
20 RIGHT :ANGLE
30 IF HEADING = 0 STOP
40 WISHWOW :ANGLE
END
```



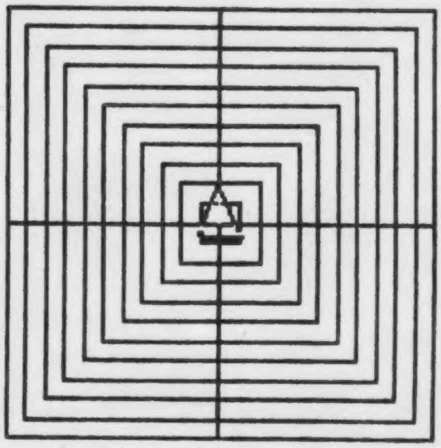
WISHWOW 160



WISHWOW 165



WISHWOW 45



WISHWOW 90

making some interesting "discoveries" about angles. If she had gone on, I would have suggested that she compare two procedures -- for example, WISHWOW and SPINBUS, with the same inputs. I would also have suggested comparing other inputs which involved simple rations (as she had already done with 45 and 90). I would have suggested some kind of chart to help organize the information she was gathering. All these things would have allowed her to consolidate her discoveries about angles.

At the end of the period, Monica expressed interest in "fixing" the christmastree (see Figure M-6). We began to work on this project as well. If Monica had returned to work on this one, I believe that she would have solidified her ideas about editing and debugging, and could have developed a stronger sense of the "step-by-step" working of the computer.

Because each of Monica's individual "projects" had been very short and simple, Monica had not developed a sense of urgency about "finishing" any of her work before the end of the series of classes. Although I can see how some important continuations, consolidations and clarifications could have occured during the next few classes, I believe that Monica had no such sense of continuity. Although she probably would have enjoyed continuing, she was also quite content to stop her work at this point.

Throughout the classes, Monica seemed to be most comfortable learning by direct imitation of examples or models supplied. In this way she learned to write procedures utilizing simple recursion, variables and stop rules. If the context was shifted, or a small mistake led to a bug, Monica was often stuck. She usually chose not to analyze her mistakes, nor did she undertake long projects requiring advanced planning, or a large number of subprocedures. Near the end of the series of classes Monica gradually began to be comfortable with editing, and to understand how to analyze a procedure in a step by step fashion.

Monica's investment in any particular project was slight -- she could easily discard it without debugging if a problem occurred, and go on to a new activity, which might prove succesful. She had a large number of small procedures, which allowed her to feel successful most of the time she was working, without having to confront her confusions. Her dribble files show numerous ideas sidetracked without debugging -- and apparently without any strong feelings of disappointment. In this way, Monica was able to function comfortably in an environment which was more complex than her understanding of it. When she did successfully assimilate a concept (as she was beginning to do with editing and debugging) she did not look back to old problems, to see if she could solve them now with her new tool. Rather, she unselfconsciously applied the new idea to whatever new problems arose. The old problems had been conveniently forgotten.

It is possible that Monica would have benefitted from being able to use a carefully designed set of worksheets structured to lead her from one concept to another with many small projects along the way.

Individual Profiles; Kathy

From the very beginning of the classes, Kathy displayed a quiet confidence, and competance in using the computer. Although not very assertive in the early group sessions, she seemed to have an excellent understanding of basics right from the start.

Kathy was extremely comfortable, with giving and receiving help. She often helped other children with the use of disks, particular elements of the LOGO language, ideas for projects, etc. She was also quite willing to ask for help when she needed it, both from the teacher and from classmates, especially Monica. In this way, Kathy was able to make steady progress in her understanding of LOGO, in her ability to conceive and carry out projects and in problem solving skills.

Kathy enjoyed working with concepts, rather than simply with practical results. Kathy was the only student among the first eight to persevere in making the computer draw a circle. We spent a lot of time, talking and playing turtle, until Kathy understood that she could make a circle by repeating FD 20, RT 20, over and over again. She rejected the idea of accomplishing this with recursion (although it would have been quicker), because (I believe) she was trying to follow through with her own idea of repeating each step, step by step. She did accept the idea of combining several of the steps into a subprocedure, and then repeating the subprocedure to make a circle. When her final result, SHELL, eventually had too many steps, and went on past the closing point of the circle, she was satisfied with it. She knew that she could have modified her circle to make it close exactly. What she had been concerned with was whether the circle would close at all. When it did, she was satisfied that she had solved her problem.

```
TO ROUND
1 FORWARD 20
2 RIGHT 20
3 FORWARD 20
4 RIGHT 20
5 FORWARD 20
6 RIGHT 20
7 FORWARD 20
8 RIGHT 20
9 FORWARD 20
10 RIGHT 20
END
```

```
TO SHELL
1 ROUND
2 ROUND
3 ROUND
4 ROUND
END
```

This is typical of Kathy's approach. She developed a concept of what she wanted to do. She asked for help when she felt she needed it. She listened to the various suggestions, and selected from them the ones she wanted to follow, in accordance with her own understanding of what the problem was about. Whatever approaches she used in her problem solving, she learned. While she often asked for help, she did not need to ask for help in those areas again.

Kathy was comfortable initating ideas for projects, and borrowing them from others -- even copying procedures directly from a booklet or bulletin board. She quickly learned that direct copying often led to unexpected problems, and she became more careful with her borrowing.

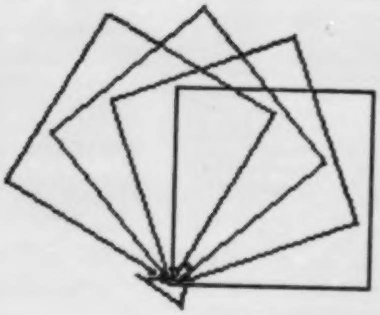
Kathy and Monica worked together a great deal (See notes about Monica) Both of them were interested in small, short-term projects, with visually pleasing results. Both depended on their mutual sharing as a source of ideas, help and reassurance. Although they often worked on the same tasks, they usually worked separately. Their approaches, and results, were different. Kathy's favorite activity was making a procedure and repeating it. Monica's was repeating a procedure and putting a rotation after each repeat. For example, Kathy borrowed a procedure of Marilyn's called HORSE in which the computer repeated the instructions, BOX, RT 20, five times. Kathy changed and elaborated it as follows:

```
TO HORSE
1 BOX
2 RT 70
3 BOX
4 RT 70
5 BOX
6 RT 70
7 BOX
8 RT 70
END
```

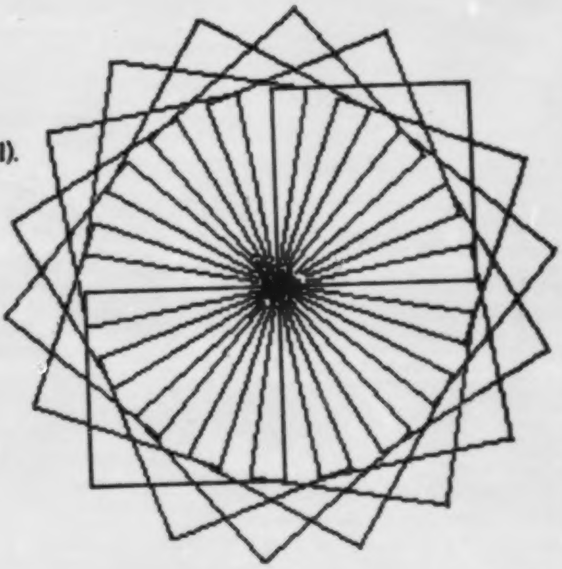
and she repeated it, using:

```
TO BARN
1 HORSE
2 HORSE
3 HORSE
4 HORSE
5 HORSE
END
```

Kathy made BARN, after repeating HORSE several times by direct command and deciding that she wanted to repeat HORSE exactly 5 times. Although she could have used recursion, she chose to limit her repeats to exactly five. She also called her new procedure BARN, introducing the mnemonic device "a barn is a group of horses." Once again, Kathy was "in charge" of what happened, using the cliche idea, "repeat a procedure over and over," but keeping control of both the process and the end result. She chose not to use recursion -- I think because she wanted to retain control (figure Ka-1).



HORSE



BARN

Figure Ka-1

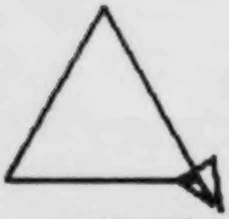
Thus when Kathy and Monica worked on similar tasks, each child brought her own specific knowledge, experience and "bag of tricks" to the project; and came out with a result that made her feel successful. Looked at in detail, we see that the girls actually functioned quite differently, and what each of them learned from the project was probably quite different. I don't think there was any great significance to the choice of angle (20 degrees for Monica and 70 degrees for Kathy). Both were simply using a number that had worked out well before. Kathy's 70 may have been just a mis-copying of Monica's 20.

If Kathy's work had an area of weakness, it was in Turtle Geometry. Kathy had difficulty estimating angles right from the start, and tended to stay away from projects that made it necessary for her to work precisely with angle manipulations. Although she and I "talked through" the idea that "when the turtle goes all the way around, it turns 360 degrees, as part of Kathy's circle project, this became an idea that she "filed" away, and did not find much use for on her own. Most of Kathy's projects involved circles and arcs, squares of different sizes, and one triangle procedure, which was one of the first ones she defined. Her specialty became combining old procedures, and repeating them in various ways to make new designs.

Kathy's TRIANGLE was used together with her BOX to make a HOUSE, repeated four times made HOUSE4. TRIANGLE repeated twice made BUTTERFLY. BUTTERFLY repeated 6 times made 7BUTTERFLY. HOUSE4 combined with 7BUTTERFLY became HB47. Later, circles were added to HB47, to make SPI. (figure Ka-2).

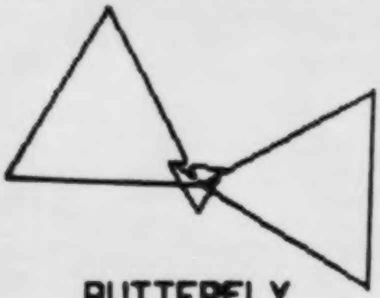
When Kathy repeated her borrowed XMASTREE procedure, she found that many repeats made a lovely, complex design. Here she was willing to use recursion, since she was not concerned about how many times the procedure was repeated in all. (figure Ka-3)

Figure Ka-2



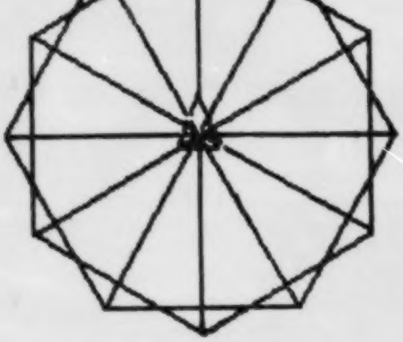
TRIANGLE

```
TO TRIANGLE
1 LEFT 90
2 FORWARD 100
3 RIGHT 120
4 FORWARD 100
5 RIGHT 120
6 FORWARD 100
END
```



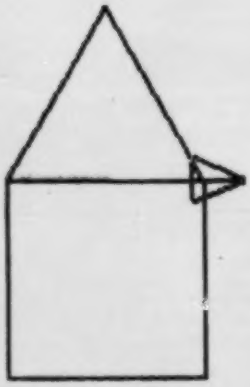
BUTTERFLY

```
TO BUTTERFLY
1 TRIANGLE
2 TRIANGLE
END
```



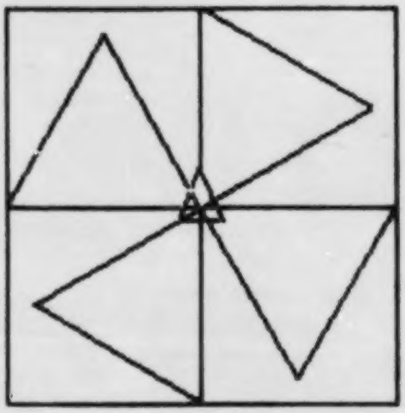
7BUTTERFLY

```
TO 7BUTTERFLY
1 BUTTERFLY
2 BUTTERFLY
3 BUTTERFLY
4 BUTTERFLY
5 BUTTERFLY
6 BUTTERFLY
END
```



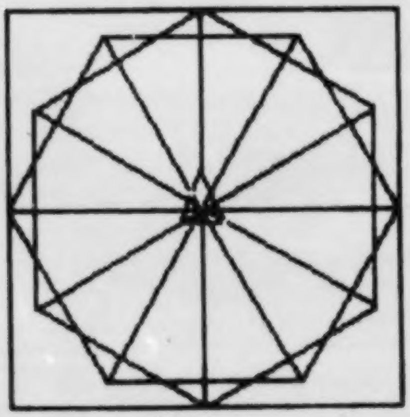
HOUSE

```
TO HOUSE
1 TRIANGLE
2 RIGHT 90
3 BOX
END
```



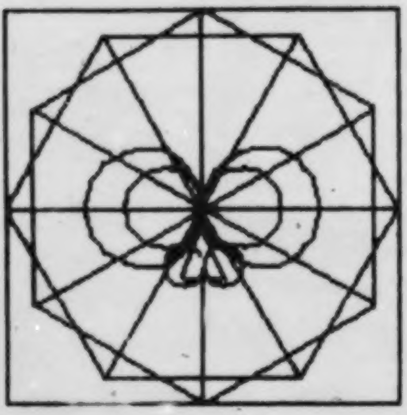
HOUSE4

```
TO HOUSE4
1 HOUSE
2 HOUSE
3 HOUSE
4 HOUSE
END
```



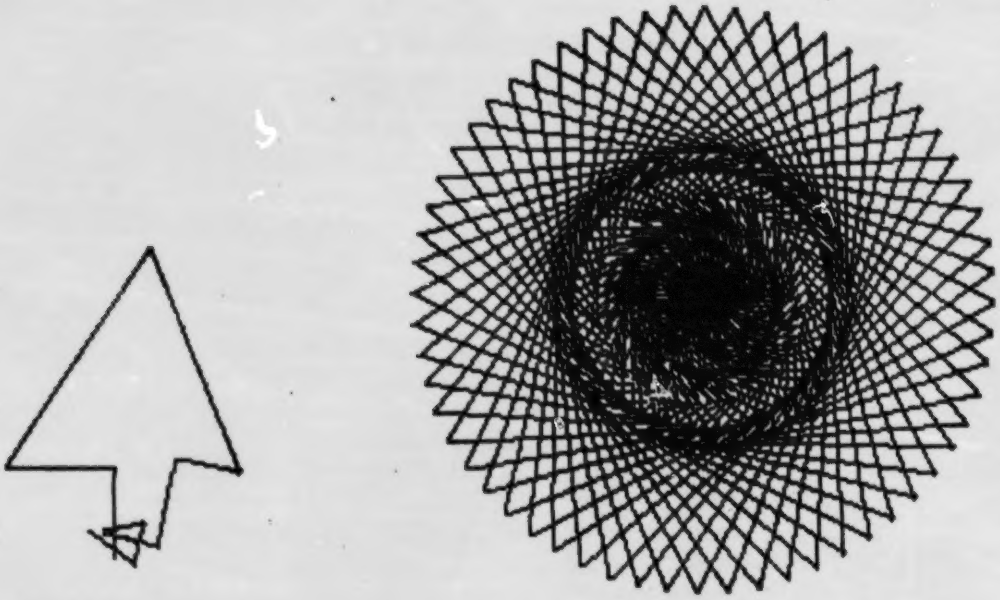
HB47

```
TO HB47
1 HOUSE4
2 7BUTTERFLY
END
```



SPI

```
TO SPI
1 HB47
2 RCIRCLE 30
3 LCIRCLE 30
4 RCIRCLE 20
5 LCIRCLE 20
6 BACK 20
7 RCIRCLE 10
8 LCIRCLE 10
END
```



XMASTREE

STAR

Figure Ka-3

Later in the series of classes Kathy did a lot of experimentation with arcs and circles, and began to work on some longer projects. They sometimes led to serious bugs which Kathy had to resolve. One day she discovered that a series of arcs "looks" like a worm," and wrote the procedures WORM and WORMY (in which WORMY is exactly twice the size of WORM). (figure Ka-4)

```
TO WORM
1 RARC 30
2 LARC 30
3 RARC 30
4 LARC 30
5 RCIRCLE 10
END
```

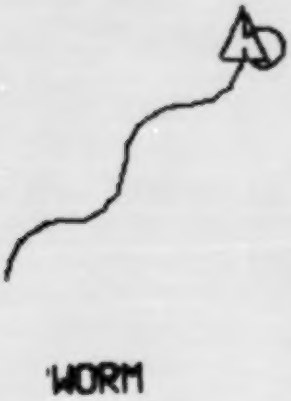


Figure Ka-4

```
TO WORMY
1 RARC 60
2 LARC 60
3 RARC 60
R LARC 60
5 LCIRCLE 20
END
```

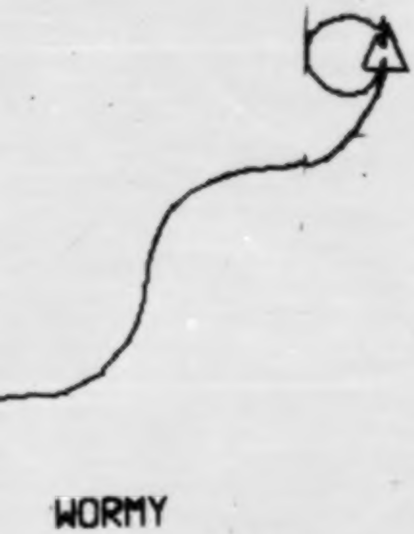


Figure Ka-4a

In a later experiment, which made use of symmetry in an unusual way, Kathy created an exotic looking "Monster." (See Figure Ka-5).

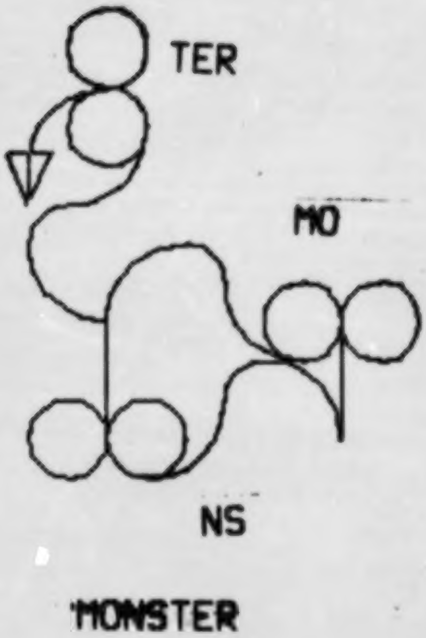


Figure Ka-5

When she decided to teach MONSTER to the computer, I suggested that she break up the project into three parts. She isolated three parts, and decided to name them MO, NS, and TER, so that her procedure MONSTER would be:

```
TO MONSTER
1 MO
2 NS
3TER
END
```

and the subprocedures were:

```
TO MO                   TO NS                   TO TER
1 RARC 40               1 LARC 40               1 RARC 40
2 RARC 20               2 LARC 20               2 RARC 20
3 LARC 40               3 RARC 40               3 LARC 40
4 LARC 20               4 RARC 20               4 LARC 20
5 LCIRCLE 20            5 RCIRCLE 20            5 RCIRCLE 20
6 RCIRCLE 20            6 LCIRCLE 20            6 LCIRCLE 20
END                     END                     END
```

I am not sure whether Kathy realized that MO and TER were identical, but in any case, she needed TER as a distinct procedure to carry through her conceptual scheme.

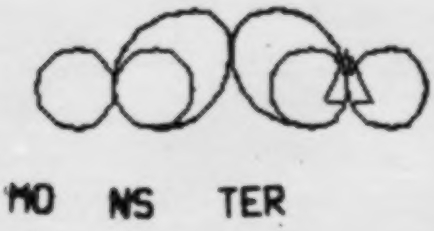


Figure Ka-6

Kathy had forgotten to include the interface steps between the three procedures, so that when she ran MONSTER, the result (found in figure Ka-6) Kathy found quite dismaying. She asked for help in debugging. I suggested running MO, NS and TER separately. When Kathy did so, she could see that the intermediate steps had been left out. Together we worked out what these steps should be, and in its final incarnation, MONSTER became:

```
TO MONSTER
1 MO
2 BK 60
3 NS
4 FD 60
5 LT 90
6 TER
7 LARC 40
END
```

Kathy's last project, carried out during classes 21 and 22, also involved symmetrical arcs, and also required a good deal of debugging. In this case, Kathy had tried out a long sequence of direct commands, and made a mistake or two in copying them into her notebook. When her procedure turned out to be buggy, she had to spend a lot of time stepping through it, in order to figure out which steps were wrong, and how to fix them. Since she had numbered all her steps by <u>ones</u>, she had to do a great deal of unnecessary retyping. I had suggested to Kathy that she number steps by fives or tens, at several points in her work, but she had never felt a need to adopt that suggestion. (In the class following this one, Kathy had a visitor, Renee, who was learning to write a procedure. When Kathy taught her, she told her to number the steps by tens. It seems that she got the point, however belatedly.)

One area of concern for me, during the classes was Kathy's lack of awareness of the effects of using different angles in various procedures. I tried to deal with this by giving her a POLY :ANGLE procedure to experiment with. While she like the designs that it made, she did not analyze the connection between the input number, and the shape that resulted. In her first session experimenting with POLY, she used the following inputs: 88, 234, 12345, 300, 344, 90, 199, 125, and 888, 666, 555, and 77 (class 10). Although she used POLY again on five other occasions, she continued to choose inputs fairly randomly.

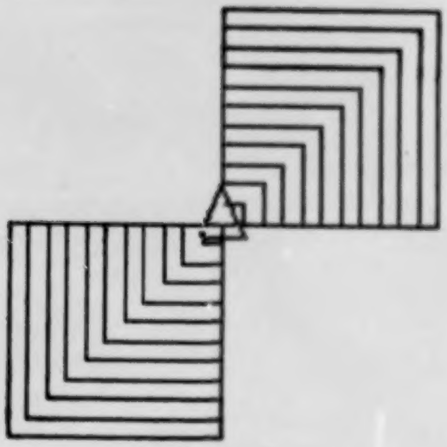


Figure Ka-7

During class 20, she was experimenting with her procedure WOW which drew a set of nested squares. She was trying to rotate this to create a particular design, (figure Ka-7) but could not figure out which angle to use to rotate WOW, despite several attempts. I decided that this would be a good point for me to suggest a focus for her. I showed her the procedure,

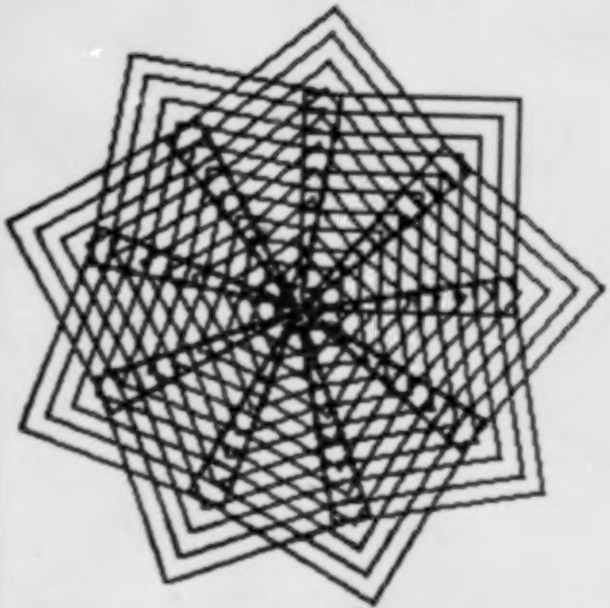
```
TO SPINWOW :ANGLE
10 WOW
20 RT :ANGLE
30 IF HEADING = 0 STOP
40 SPINWOW :ANGLE
END
```

This was meant to serve as a vehicle for exploring angles, and for furthering her understanding of variables and STOP rules.

At first she chose inputs like 900, 9999, 777 and 666. At the beginning of the next class, I spoke to her about "interesting angles," reminding her that the turtle turns all the way around in 360 degrees. I suggested that numbers that divided evenly into 360 degrees might be "interesting numbers". I also suggested that she spend the period experimenting with SPINWOW, and taking notes on the results.

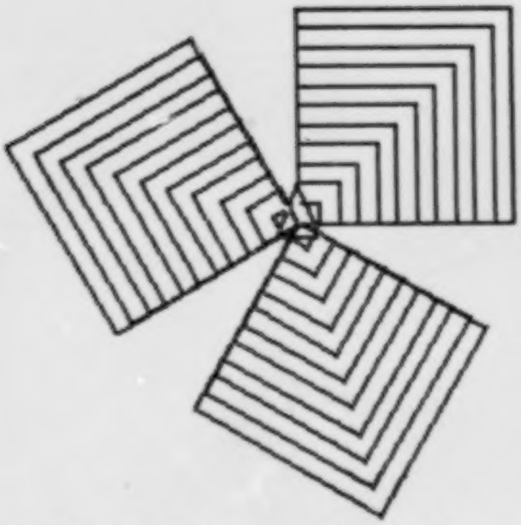
Initially Kathy took me at my word, and began using inputs that were factors of 360, like 4, 12, and 18, 60 and 90. She quickly branched out to 100, 200, 400, etc. Since she had been specifically asked to take notes on the results, she paid careful attention to what was happening, for the first time. For example, she counted the number of "cones" that appeared in the designs, and this showed her that certain figures (SPINWOW 200 and SPINWOW 400) looked "the same". Her notes, entitled "Interview with SPINWOW'S" are copied from her notebook (see figure Ka-8). (compare this with Monica's work with her procedure WISHWOW).

Figure Ka-8

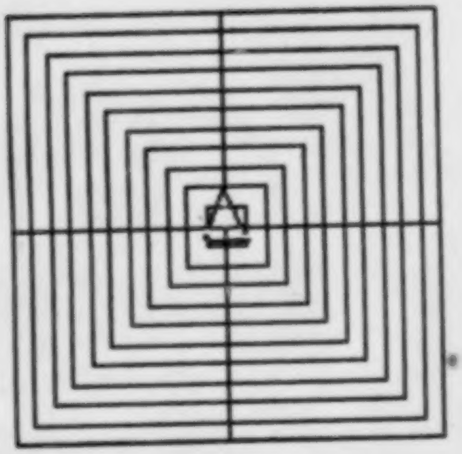


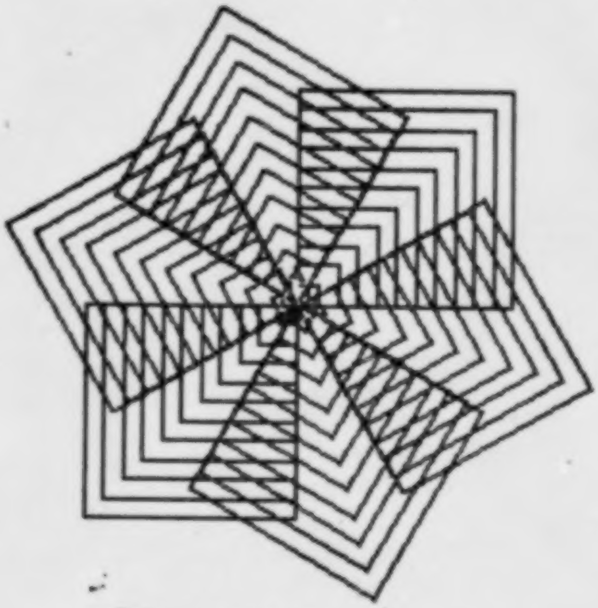
SPINWOW 40

SPINWOW 200 SPINWOW 400



SPINWOW 600 SPINWOW 120





'SPINWOW 60

SPINWOW 90

Interview with SPINWOWS

SPINWOW 40: it had 9 points it looked like a spiders web.
SPINWOW 200: looks exactly like spinwow 40.
SPINWOW 400: looks exactly like the two above.
SPINWOW 600: it has three points looks like a martian face.
SPINWOW 120: looks like SPINWOW 600 has that martian face look.
SPINWOW 30: it has 12 points looks like a combined thing of a snowflake and a spiders web.
SPINWOW 90: it just makes a biger wow
SPINWOW 140: it has about 17 points looks like a snowflake.
SPINWOW 60: looks like a wow that was done 6 times has 6 points.

. . . .

Kathy liked to initiate new projects, was comfortable with new ideas, and enjoyed the challenge of working on something to which the answer was not known in advance. She accepted the existence of bugs - even coined the phrase "exterminating" to replace "debugging" -- and was willing to work to resolve them. On the other hand, she usually chose to work on small projects, and to carefully limit the tools required for any task that she set herself. This was her way of remaining in control of her work, making sure that her experience was not too confusing for her.

If Kathy had had the opportunity to continue with her classes, I'm sure that I would have continued to stress working on projects using angles as variables. Also I would have tried to lead Kathy into at least one long term project that required advanced planning and the use of subprocedures. More work in these areas would have nicely rounded out her LOGO experience.

Individual Profiles; Ray

From comments made by his teachers, and from observations made by myself and others in the LOGO classes, I have a model of Ray as a boy who has chosen to react to academic difficulties by adopting a pose of indifference, and refusing to take responsibility for his work or behavior in school.

From the first day he came to class, in session 2, Ray insisted on remaining "aloof"; preventing himself from feeling personally involved with the LOGO activities. Although he started off quite successfully, and actually was generally successful under close supervision in his first programming project -- causing the computer to draw his initials -- he maintained his "cool" until the last four or five sessions, when he began to allow himself to become interested in what he was doing.

Before summarizing his work, it would be useful to list some of his techniques for maintaining and reinforcing his posture of aloofness from the activities. He began by coming four or five minutes late for each class. By coming to class late, he guaranteed that I would be already working with another student. Thus he could waste several more minutes waiting for me to remind him how to LOGIN, and start him with a suggestion for his day's work. He often walked into class whistling loudly, blatantly disregarding anything else that was going on. He made a point of always leaving a few minutes early, and as he worked on activities, he would look at the clock, to see if it was time to leave yet.

Ray made a point of not remembering how to do things. He would not write things down in his notebook, and when asked to consult a reference sheet or an entry in his notebook, he would usually just sit there, and wait for personal help from me or one of his classmates -- usually Gary. This was his way of reinforcing a sense of helplessness, of "I can't do it", of dependency on the teacher. Rather than maximizing his use of available resources, Ray deliberately minimized them.

Ray refused to learn the details of operation of the system and the language. Not until class 12 did he LOGIN by himself. He never wrote a file without assistance. Likewise, he never wrote a procedure without help. Although he was introduced to the REPEAT command, and used it to make turtle designs that were quite pleasing to him, he never remembered the format for using it, and would not look it up.

I am quite seriously using words like "refused to learn", "techniques for maintaining aloofness," "made a point of not remembering," because I am convinced that these were definite strategies of his, to protect himself from involvement, rather than a "sincere" inability to concentrate or learn.

From my conversations with Ray's teachers, I learned that he uses similar strategies in his other school activities. Ray is diagnosed as a boy with "learning disabilities." He is reported to be reading at a "first or second grade level." He has individual tutoring at the school's "learning center" several times each week. One of his teachers told me: "we are all very upset about Ray because we feel that he is 'slipping through our fingers'." When I reported that Ray had been absent for four of the first eleven classes, she asked me to check the school attendance records to see if Ray was "cutting", a practice which he has been developing lately as a response to his first year of "departmentalized" classes.

At the same time, Ray is clearly intelligent, attractive and charming. He has a definite natural aptitude for music -- he enjoyed spending time tapping rhythmically, whistling, and improvising intuitively on the piano.

I would like to speculate that from his earliest school experiences, Ray has been afraid of failure, and especially of appearing to fail. His strategy for coping with this has been the "class clown" approach -- act a little bit silly, charm everyone, and above all, don't let anyone know you're trying. My strategy with Ray was to try to structure situations so that he would be successful, and develop a sense of confidence -- a sense that he could do it. I did this both by helping him with a special animation project, (which in the end proved too complex, requiring too much of my help) and by trying to set up situations in which he could be sucessful with very little input. The latter approach proved to be the best for Ray, as I will describe in the detailed description of his work, which follows.

Despite his difficulties, Ray was interested in the computer, and its power. He showed a good deal of "natural ability" in turtle geometry, which made me quite hopeful about him at first. Ray was very successful in directing the turtle, estimating quickly and accurately, both angles and distances. His first project was making his initials, and he carried it out quite successfully, combining skill in turtle geometry with a quick understanding of using the keyboard, and it seemed, understanding of how to write procedures. (See figure R-1)

```
TO RG
1 PENUP
2 LEFT 90
3 FORWARD 70
4 RIGHT 90
5 PENDOWN
6 R
7 PENUP
8 LEFT 100
9 FORWARD 100
10 RIGHT 60
11 PENDOWN
12 FORWARD 70
13 BACK 70
14 RIGHT 90
15 FORWARD 90
16 LEFT 90
17 FORWARD 70
18 LEFT 90
19 FORWARD 40
20 LEFT 90
21 FORWARD 30
END
```

```
TO R
1 FORWARD 100
2 RIGHT 90
3 FORWARD 50
4 RIGHT 90
5 FORWARD 40
6 RIGHT 90
7 FORWARD 50
8 LEFT 140
9 FORWARD 87
END
```

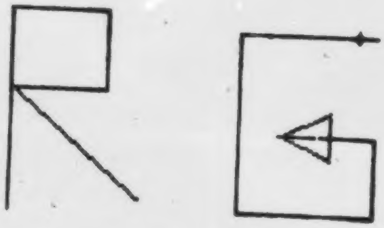


Figure R-1

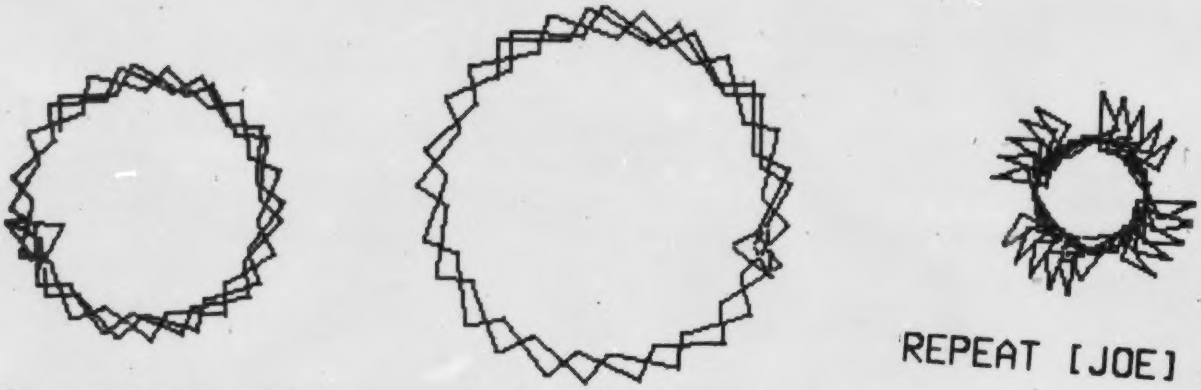
As Ray went on beyond this project, however, I found many difficulties impeding his progress. He would rarely work purposefully unless I was present. All his further turtle geometry explorations appeared to be random. He did not remember how to write a procedure, and refused to "look it up", in his notebook. He never wrote a procedure when I was not present! I tried to solidify his understanding of procedure writing by showing him how to make a procedure out of two or three turtle steps, and the use REPEAT to make designs. He made several simple designs -- SAM, TIM and JOE. I found that he still did not remember from time to time, how to make a procedure, or how to use the REPEAT command. Again, he refused to look it up in his notebook.

After completing his initials project in class 4, Ray's work in classes 6-12 was characterized by short bursts of activity -- especially when I was present -- and frequent visits to the water fountain, and to the piano in the next room. Ray was absent for classes 5, 7 and 10. What I found that Ray did do successfully on his own was to experiment with different inputs to REPEAT. He would use sequences like REPEAT [SAM]90, REPEAT [TIM] 30, REPEAT [JOE] 20, REPEAT [SAM] 30, etc. (See figure R-2)

```
TO SAM
1 FORWARD 17
2 RIGHT 90
3 FORWARD 29
4 LEFT 56
END
```

```
TO TIM
1 FORWARD 19
2 RIGHT 90
3 FORWARD 36
4 LEFT 61
END
```

```
TO JOE
1 SAM
2 LEFT 150
3 TIM
END
```



REPEAT [SAM] 30

REPEAT [TIM] 30

REPEAT [JOE] 20

Figure R-2

After doing some of these, he'd return to ones he liked. It seemed that he could focus for a short time on the task of choosing inputs to REPEAT, although he could not remember how to use REPEAT from class to class. By class 12, however, this approach had lost interest for Ray, and it became clear that it had not resulted in his being able to write procedures independently, as I had hoped.

In session 13, I suggested an animation project to Ray. He agreed, and decided to animate a rocket. Session 13 was spent drawing the rocket. I spent a major part of the period working with him, first helping him figure out how to draw a triangle (see fig. R-3), and then helping him organize the task of teaching his rocket to the computer. His ROCKET procedure had two subprocedures, TOP (triangle) and ROCK (rectangle). (See figure R-3)

```
TO ROCKIT
1 TOP
2 ROCK
END
```

```
TO TOP
1 RIGHT 90
2 FORWARD 60
3 LEFT 120
4 FORWARD 60
5 LEFT 120
6 FORWARD 60
END
TO ROCK
1 LEFT 30
2 FORWARD 90
3 LEFT 90
4 FORWARD 60
5 LEFT 90
6 FORWARD 90
END
```

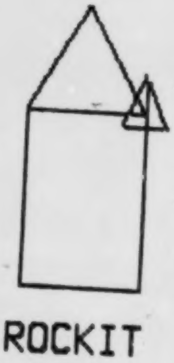


Figure R-3

In class 14, I again worked closely with Ray. We worked through the process of animating the rocket. He decided that his ROCKET was too big, so I helped him make a smaller, scaled down version, which he decided to call FB. His procedure to move the rocket was called NKP. I introduced Ray to the idea of SNAPs. He understood how they were used to animate the motion -- but of course he had difficulty remembering the format for using SNAPs. I had the distinct sensation that I had introduced too much material during this class.

In class 15, I again spent a great deal of time with Ray. He was not especially interested in varying the WAIT and Distance for the animation (I had given him a procedure which he could use to do that easily), but he was interested in making the rocket turn. I printed out his animation procedure NKP, and we figured out together where he could put a turn command, to make the rocket turn on the screen. While still in edit mode, Ray experimented on his own with different inputs for the turn: RT 300, RT 66, RT 2, RT 3, etc. He finally settled on RT 3, as the largest number he could use without having his rocket go off the screen. He then typed END, followed by GOODBYE (without a WRITE command).

It was in analyzing the dribble file from this class that I became strongly aware that Ray had been consistently successful in activities that required varying only one paramter at a time. I began serious consideration of how to use this observation to get Ray involved in a more consistent relationship with his work.

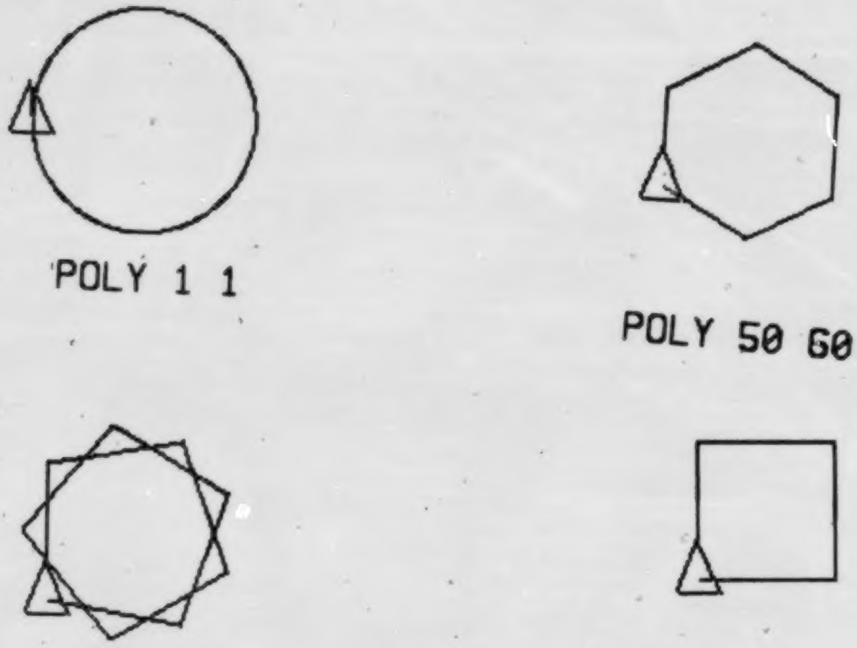
Class 16 was spent in a whole class discussion about the story "ZEEP and the paint". Ray was determinedly aloof. Ray spent class 17 working with Jeanne on the pattern block task, and at the piano. Class 18 was mostly wasted. I tried to get Ray to use recursion, but he said "I don't like designs." I also tried to start him on another turtle geometry project, but when I went to spend time with another student, that too fell flat.

It was decided to introduce Ray to the LOGO music box, during the following week, to try to capitalize on his interest in musical improvisation, and to give Ray a special sphere of activity, in which his work would not be compared with anyone else's. This did not work out because of breakdowns in the MIT LOGO system, to which the music box was to be connected, via remote terminal.

In class 19, I decided to just give Ray a POLY procedure, with a simple stop rule, and let him experiment with changing the inputs. In this way, he would have only one thing to consider -- the choice of numbers to make interesting designs. This was a successful choice and he continued to work with POLYs and a POLYSPI type procedure for the next six classes.

In working with POLY during classes 19 and 20, Ray tended to choose inputs based on "number patterns" rather than on the effects produced by the POLY procedure itself. For example, during class 19, the POLY inputs he chose were (see Figure R-4):

SIZE	ANGLE	
556	889	increasing and decreasing sequences
765	987	
567	987	
1000	2000	
999	999	
1	1	he was intrigued by the fact that
2	2	these made circles
3	3	
50	60	surprise! hexagon!
70	80	
70	89	he really likes this
70	90	I showed him this one, to go with it.



POLY 1 1

POLY 50 60

POLY 70 80

POLY 70 90

Figure R-4

In class 20 I made a point of showing him that the first number effects the size, and the second number the shape. His work was still based on number patterns.

SIZE	ANGLE	
678	987	
70	89	an old friend
40	40	
50	50	same numbers
60	60	
78	93	
1	1	
1	34	makes a bright dot
98	89	reversing digits
567	123	
1000	1000	same input
200	7820	
678	876	reversal
9000	9000	same
765	897	
850	850	same
100	850	here I showed him the effect of
200	850	changing the first input, while keeping the second constant.

In class 21 I showed Ray a spiral procedure, SPI:SIDE:ANGLE, and later edited it to make the increment a variable as well, SPI:SIDE:ANGLE:GROW. For the first time, Ray began to experiment with the effect of the changed input, by varying the rate of growth of the spiral. First Ray experimented with small numbers like SPI 1 1 and SPI 3 4. Even with inputs like SPI 22 33, Ray found the shapes "boring", because they all went off the screen so fast. I suggested larger numbers for the second input, and Ray tried things like 1 100, 2 200, 3 300, and 4 400. I showed him the relationship between POLY and SPI by putting POLY 100, 200, and SPI 2 200, on the screen one after the other. (See figure, R-5)

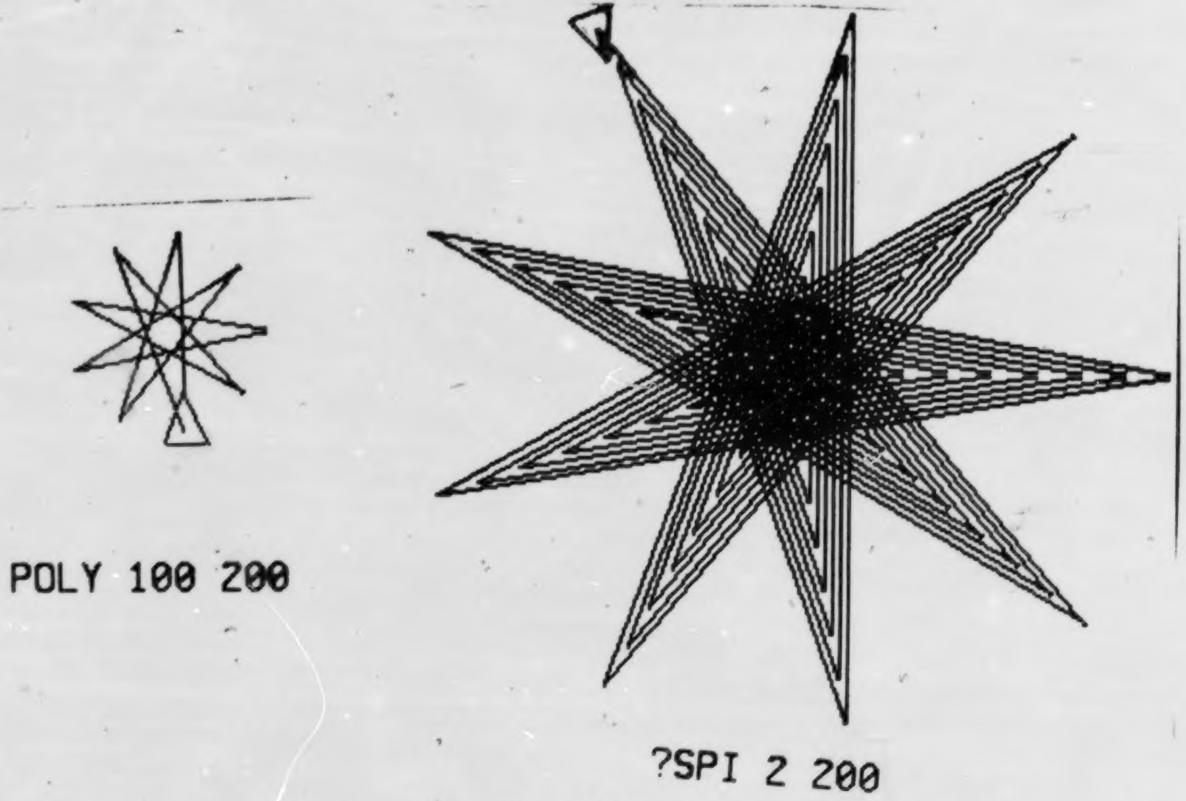


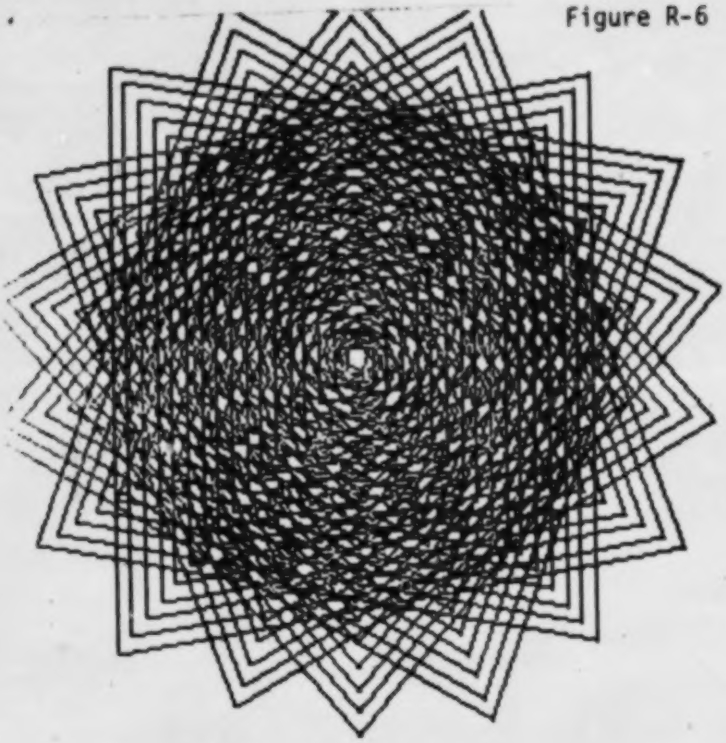
Figure R-5

Ray was a lot more interested now, but he still felt that they went off the screen too quickly. I edited SPI to allow changes in the increment, adding the variable GROW, and I showed Ray how to use it.

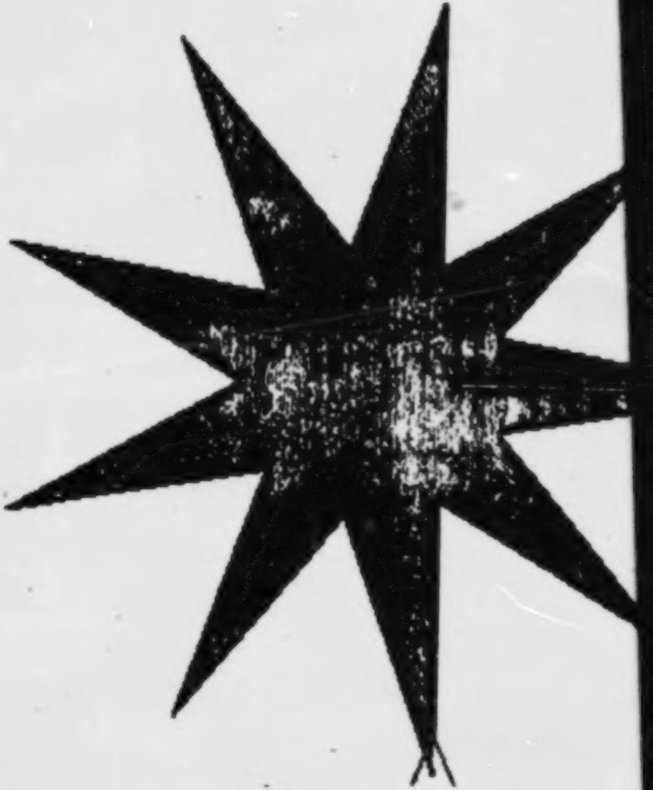
Ray liked the effect of the tighter spirals -- especially the emergent designs, which became apparent with small increments. He tried 1 400 1, 1 400 3, 1 401 1, focussing now on the effect of changing the numbers, rather than on the numbers themselves.

Ray came in with his idea for class 22: "Can I put SPI and POLY together?" (I told him he could if he used the POLY first.) I had also made up a worksheet for him which listed a few POLY and SPI designs, and left space for him to write down some "interesting" numbers of his own choosing. He worked with these activities for a solid hour, asking for help at only two points, writing down several "good numbers" on the chart I had given him. He liked one of the designs a lot, SPI 10, 150, 2, and called people over to see it. At the end of the class he spontaneously punched holes in his papers and put them carefully in his notebook. Today Ray's explorations were much more systematic: changing only one

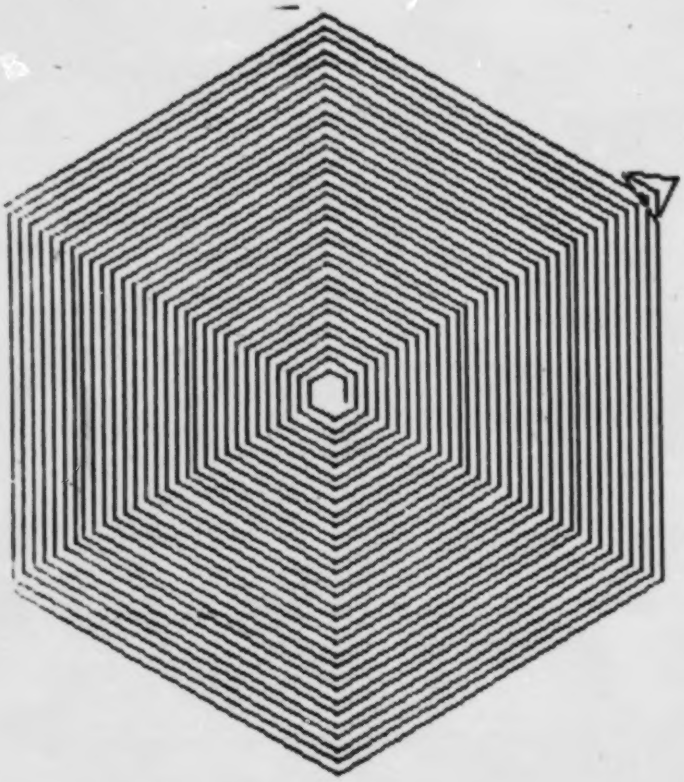
Figure R-6



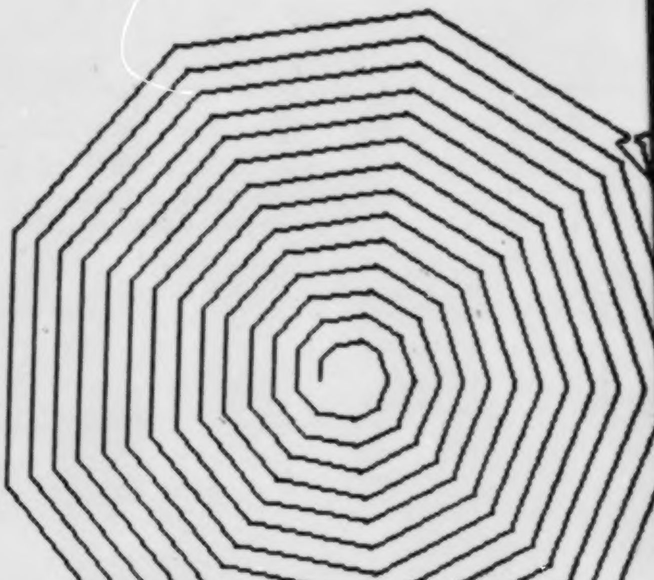
SPI 10 100 1



SPI 10 200 1



SPI 10 300 1



SPI 10 400 1

variable at a time.

POLY		SPI		
SIZE	ANGLE	SIZE	ANGLE	INCREMENT
50	100	10	30	2
50	35	10	45	2
50	49	10	150	2
		10	300	2
		10	100	1
		10	200	1
		10	300	1
		10	400	1
		10	500	1
	Ray's Favorite	10	150	1

(See figure, R-6)

In session 23, I gave Ray another procedure, LPOLY, with which he could make symmetrical shapes. After using this a while, he went back to SPIs. This time, focussing on the emergent spirals. He had drawn SPI 1 250 2, and when I suggested making a small change in the "middle number", he followed through by using 245, 235, 225 and 215, in sequence. I also showed him how varying the third input could create quite different effects, by decreasing the density of the design. (See figure R-7)

In this class, Ray began to use animation again as well. He was finally becoming comfortable with the computer. Although he was not defining procedures, he was engaging in significant mathematical explorations, and, best of all, feeling that he was in charge.

In session 24 he continued to use right and left POLYs some of his favorite SPIs, and animation. He learned that he could animate anything, using his NKP procedure, just by typing MAKE "FB SNAP, and then typing NKP -- which would animate whatever had been on the screen. He also asked me to write down the WRITE command in his notebook.

At the end of the period, he came over to where Gary was working and asked what he was doing. This was the first time he had taken an obvious interest in anyone else's work. In addition, he very carefully made sure to remind Gary: "better make sure to write your file before you say GOODBYE" thus letting it be known to one and all that "he knew what it was all about" as well as anyone.

The next class was "visiting day" and Ray brought Paul, a seventh grader. He showed Paul how to use POLY and SPI procedures and a few other procedures: NKP, SAM and RG. Together they tried out different inputs to POLY and SPI. Ray both referred to his notebook for ideas about what to try, and wrote down new ideas as he went along. Ray stuck stricktly to what he was comfortable with: POLYs, SPIs and moving his rocket. He and Paul had a wonderful time, and both came away feeling wonderful.

This turned out to be Ray's last class. He truly went out in a "blaze of glory". I feel that if I had understood how afraid of failure Ray was, and how important it was for him to have only one thing to vary at a time, I could have gotten him "hooked" much earlier. Although he did not define any more procedures of his own, or do any "planning and debugging", Ray had finally achieved the first prerequisite for any success with the computer. He had found a way to be in charge. I honestly believe that continued progress would have been made, if there had been several more classes.

One last "footnote" about Ray. When the classroom teachers were interviewed, they felt that the computer experience had had a profound effect on Ray. A quote from one of his teachers:

> "There was a breakthrough with Ray...He hasn't connected all year...been floating, not that there is any resistance or hostility, but just no connection...(he) was probably swamped by the reading required this year...The breakthrough for him in LOGO, the success he has had, is powerful information for me...he has produced the best piece of writing I've seen from him...His physical arrangement has changed, he was isolated in the room before, now he sits with others."

Appendix II - Detailed Analysis of Each Child's Learning in the Area of Computer Programming

Acquisition of Programming Skills

This section of the report surveys the students' acquisition of Logo programming skills. In surveying this material, one should bear in mind that the students' learning took place in a ***project oriented setting*** and no attempt was made to expose all students to the same "standard Logo curriculum." Rather, the teacher introduced new Logo material to students on an individual basis, and in a way which would be integrated in their individual projects. Consequently, we observed different students concentrating on different aspects of Logo. For example, some organized most of their learning experiences around the creation of free-form "emergent" designs, while others concentrated on elaborately planned projects. Most of the students' work related to computer graphics, but a few also undertook non-graphics projects. The eight students in the experimental group spanned a wide range of interests and cognitive styles. One of the strengths of this kind of Logo learning environment is that it can appeal to students across such a spectrum and allow for projects that can be of interest to each of them.

In summarizing the students' programming experiences, we shall first describe, on a student by student basis, the individual progress over the 24 class sessions. After this, we shall summarize the students' introduction to and use of various elements of Logo programming

GROUP I: STUDENT -- LIB

Sessions 1 and 2: There was only one terminal available, and Laura worked together with Gary. They experimented with the ***basic turtle commands*** and learned how to write simple ***procedures*** (without inputs), for example,

```
TO FOO3
10 BK 25
20 RT 15
30 FD 10
END
```

They were also exposed to the REPEAT command and played around with the symmetric designs that emerged from repeating procedures like FOO3. During the second session they (but mostly Gary) began to use things like FOO3 as ***subprocedures*** in design drawing programs:

```
TO FOO4
10 FOO2
20 REPEAT [FOO3] 24
END
```

Session 3: No terminal available for Laura to work at. She worked at planning designs on paper. Began planning a procedure to draw here initials and wrote down a few steps in her notebook.

Sesson 4: Worked at the teletype (no display terminal available) mostly experimenting with ***print*** and having lots of fun getting the computer to print out long nonsense statements. These were all done with direct commands (no procedures defined).

Sessions 5 and 6: This was the first time Laura had a terminal to herself. She experimented with drawing designs (again, all direct commands, no procedures defined) and also used the *circle* primitive. She also played some more with print.

Session 7: A big step. Laura moves from playing somewhat randomly with direct commands to settling upon and *planning a project*. Teacher introduced the idea of using different *subprocedures* for different parts of the face. By the end of the period she had completed NOES [sic], RIGHTEYE and LEFTEYE.

Session 8: Completed the face with MOUTH and drawing a square around the whole thing:

```
TO FACE
1 NOES
2 RIGHTEYE
3 LEFTEYE
4 MOUTH
5 SQUARE1
END
```

Note that lines are numbered by 1's, not by 10's.

Session 9: Laura went back to working with designs, but in a more planned and purposeful way than previously. This was her first real exploration of the possibilities of different sized circles, and she made an elaborate circle design:

```
TO AROUND
10 LCIRCLE 90
20 LCIRCLE 58
. . .
90 LCIRCLE 66
END
```

She's also adopted numbering lines by 10's.

Session 10: Taught the computer the mirror image of AROUND (right-hand rather than left-hand circles) and put the two designs together. Rest of period as spent playing with the *arc* command and making designs with arcs.

Session 11: Very carefully *planned, programmed and debugged* an elaborate project consisting of turtle designs. She had to pay attention to the *interfaces* between the circles. The design also made use of a *planned subprocedure*.

Session 12: Teacher capitalized on Laura's interest with designs to introduce *inputs* and *simple recursion* as a way of repeating designs. She wrote a procedure which drew a cricle, turned and then repeated.

Sessions 13-15: Lots more work with recursion and inputs. During session 13 she defined a peocedure to draw a variable sized square. In session 14 the teacher showed her how to incorporate this into a *recursive procedure with changing inputs* to produce a "growing square." Session 15 was spent re-trying old procedures.

Session 16: Devoted to a class lesson. ("Zeep story")

Sessions 17-18: These were spent working on a Madlibs project. She began by following the teacher's suggestion to write a story and underline the words to be replaced by random words. Next she worked with the teacher on classifying the underlined words according to part of speech. Then she put together the basic procedure which typed the non-random part of the story and had subprocedures called VERB, NOUN, ADJECTIVE, etc. which would select the random words. Then the teacher told her how to use ***make*** to construct ***lists*** of verbs, nouns, etc. and the teacher supplied a procedure which chooses random elements from a list.

Session 19: Completed debugging of Madlibs game and dropped it to go back to designs. (Did the teacher introduce too much too fast in the previous 2 sessions?) Began working on a procedure which takes ***two inputs***, size and angle, and experimented with various sizes and angles.

Session 20: absent

Sessions 21-23: These were spent mostly debugging a procedure which made use of a ***stop rule***. Laura got involved with a complicated bug: the idea was to repeat a basic design until the turtle's ***heading*** was equal to zero. However, there was no net heading change over the basic loop of the design, and so the stop condition was never satisfied. The bug was finally resolved by changing one of the angles at one of the steps in the loop.

Session 24: absent

Session 25: Laura wrote a program to draw her initials, using separate procedures for each of the letters.

GROUP I: STUDENT -- GEM

Sessions 1-2: Gary and Laura worked together at one terminal. (See above.)

Session 3: No terminal available for most of the period. Gary worked on ***planning on paper*** a procedure to draw his initials.

Session 4: Gary worked at the teletype. Teacher introduced PRINT and arithmetic. Copied from worksheet a procedure for drawing a box on the teletype. Also played with arithmetic:

```
TO HELLO
1 PRINT 374*.4537
END
```

and, following a model on one of the worksheets, made this repeat by ***simple recursion***:

```
TO SUPERHELLO
10 HELLO
20 SUPERHELLO
END
```

Session 5: Gary's first day alone at the terminal. Uses ***circle primitives*** and makes a design which looks like the eyes for a face.

Session 6: Finishes face design, adding nose by direct commands.

Session 7-8: Gary's first long period with a terminal to himself. Re-does his face by doing *top-down planning*. He accepts teacher's suggestion of using procedures *functional names* (FACE, MOUTH, NOSE), although adopts it to his own wry style of naming all procedures FOO. For example,

```
TO NOSE
1 FOO7
END
```

Session 9: Gary begins playing with the SPIN command. Teacher introduces both *inputs* and *simple recursion* and Gary writes

```
TO TURN3 :ANGLE
10 FORWARD 100
20 RIGHT :ANGLE
30 TURN3 :ANGLE
40 HIDETURTLE
END
```

(He doesn't notice that line 40 never gets executed.)

Session 10: Period began by playing with the *arc* primitives. Gary later decided to have the computer do math, and make a math quiz. Teacher introduces *random, test, stop, typein, sentence* and *make*.

Sessions 11-12: These are spent elaborating and debugging the math quiz. The final version can handle two digit numbers and prints its questions in column format. Smaple output:

```
WELCOME TO THE WORLD OF MATH!
  74
+
  94

--------
<168     (user types answer here)
CORRECT!
WOULD YOU LIKE TO HAVE ANOTHER PROBLEM?
<YES
O.K. HERE WE GO AGAIN!
etc.
```

Sessions 13-16: These were devoted to planning and debugging a starship which can move and turn in response to keys pressed at the keyboard. Teacher introduced *snaps* and Gary wrote a *two input procedure* which moves the starship forward a specified distance at a specified speed.

Sessions 16: Mostly spent in class activity.

Session 17: Worked for most of period on "articulation task" and showed some of his procedures to a visitor. Also editied his procedure which moves the starship to change its name to MOVE. (It's original name was ANYTHING.)

Session 18: Spent mostiy watching movie. Also played with some animation primitives.

Session 19: Mostly playing around in a non-directed way. Says he has an idea for a project that he got from a computer book -- to have the computer understand morse code.

Session 20: Preparing notebook for parents' visit. Brings in computer book to discuss morse code project with teacher.

Session 21: Brings in morse code listing and writes basic procedure for translating code:

```
10 IF :LET = "A OUTPUT [.-]
etc.
```

(First use of ***output*** and ***quotes***.)

Session 22: Teacher introduced ***first*** and ***butfirst*** and talked through with Gary how to decode a word. Gary used that as a model for a procedure to decode a whole message:

```
TO PRI2 :MES
5 IF :MES = [] STOP
10 PRI FIRST :MES
20 TYPE [%%%]
30 PRI2 BUTFIRST :MES
END

TO PRI :WORD
5 IF :WORD = " STOP
10 TYPE CODE FIRST :WORD
20 TYPE [%]
30 PRI BUTFIRST :WORD
END
```

First use of ***real recursion***. Also ***empty word*** and ***empty list***. Gary comments "Today was a good day!"

Sessions 23-24: Adds an debugs an encoder to the morse code project.

Sessions 25-26: Brings visitor and works with him on creating a "Zeppelin" design and animating it.

CLASS I: STUDENT -- Deborah

Session 1: absent

Session 2: Works on drawing a square. Very unsure of herself.

Session 3: Defines square as a procedure.

Session 4: Begins to plan on paper a procedure to draw her initials. Still constantly seeks assurance from teacher. (Example: She asks teacher to draw the letters for her. Teacher replies he is sure that she can do it.) Finally with teacher's help types in procedure to draw the D.

Sessions 5-7: Continues to work on initials. Still attempts to monopolize teacher's attention.

Session 8: Teacher gives her an assignment to experiment with ***arc*** primitives. This is Dim's first real exploring and she makes ***free-form designs*** using direct commands.

Session 9: A breakthrough! Deborah continues to explore with arcs, and makes a spiral -- her first ***purposeful design***. At end of class declares "I didn't need any help today." Teacher's analysis: "I'm convinced that her problem with the initials project was its complexity and the necessity of a successful completion. Making designs has no such stigma attached."

Session 10: Continues to work on her own. Defines her first independent ***procedure***, which draws her spiral. Then worked on drawing a man -- her first independent ***planned design***.

Sessions 11-13: absent

Session 14: Continues her man design right where she left off. Uses arcs to write a ***subprocedure*** to draw the eyes.

Session 15: Made a "flower design" by having the turtle draw a circle six times. Teacher introduced ***simple recursion*** to make the process repeat more, but Deborah wasn't interested. Said she just wanted to "goof around."

Session 16: class activity. Says she wants to make a rabbit, and makes a drawing.

Session 17: Starts the class working on the rabbit by direct commands. Eventually stops this and defines a procedure which repeats a flower design:

```
TO BLUE
1 FLOWER
2 RIGHT 90
3 FLOWER
END
```

Asks teacher: "Was this what you were trying to show me yesterday?" (Referring to the recursion example.)

Session 18: Class views film on computer graphics. Deborah gets from the film the idea of making a six-pointed star. The program contains her first real use of functional

subprocedures:

```
TO TRYANGLE
2 FORWARD 70
3 RIGHT 60
4 RIGHT 60
5 RIGHT 70
END

TO STAR
1 RIGHT 30
2 TRYANGLE
3 LEFT 60
4 TRYANGLE
. . .
```

Sessions 19-20: Started again to work on her rabbit. Wrote ***subprocedures*** HAT and LITTLEEYES.

Session 21: absent

Sessions 22-24: Completes rabbit, adding procedures for NOSE, EARS, FACE and a superprocedure called RABBIT.

Session 25: Came in and made the turtle draw a sqaure in only two attempts. Then wrote a procedure to draw a diamond. (See discussion on perception of tilted square as diamond.) Teacher showed her how to repeat this by ***Iteration***

```
TO PIN
5 DIAMOND
10 GO 5
END
```

Session 26: Showed procedures to her parents, who visited class.

GROUP I: STUDENT -- Ray

Session 1: absent

Session 2: Experiments with basic turtle commands and draws a rectangle.

Session 3: Began to work on drawing his initials. Completed the R by direct commands.

Session 4: Completed the G by direct commands. Combined this with the R by writing ***procedures*** R and RG.

Session 5: absent

Session 6: Shared terminal with Gary. didn't do much.

Session 7: absent

Sessions 8 and 9: Ray's first time with a terminal to himself. Teacher suggested writing a small procedure and using *repeat* to make designs. His procedure was:

```
TO SAM
10 FORWARD 17
20 RIGHT 90
3 FORWARD 29
4 LEFT 56
END
```

He explored with REPEAT [SAM] different numbers of times. Then wrote another procedure

```
TO TIM
1 FD 19
2 RT 90
3 FD 36
4 LT 61
END
```

and was disappointed that the results were so much like SAM. Teacher showed him how to combine the two

```
TO JOE
1 SAM
2 LEFT 150
3 TIM
END
```

Session 10: absent

Session 11: More repeating designs. Asked the teacher whether he had to use "names I already know," and the teacher said he could just as well use something like Q16 -- so Ray called his procedure Q16. He wrote:

```
TO PQ
1 Q16
2 FORWARD 89
3 Q16
4 FORWARD 89
5 Q16
6 FORWARD 89
7 Q16
END
```

Teacher also suggested making a triangle. Ray worked on this a short time and gave up. Ray is still very dependent on the teacher. Does not remember how to login, use repeat, or write a procedure without help.

Session 12: Ray worked pretty randomly, making a design by direct commands. when asked what he was making, he replied "Who knows?"

Session 13: Ray's first *project*: he wanted to make a rocket and animate it. The first time he had come in wanting to work seriously on something. Defined two procedures TOP and ROCK which, together, drew the rocket.

Sessions 14: More work on the rocket. Began by wanting to make a smaller rocket. Teacher decided not to introduce variables, but rather, told him he could copy his rocket procedure changing the lengths of the sides. Teacher introduced the DISPLAY, WAIT, WIPEOUT, FORWARD, DISPLAY method of ***animation***.

Session 15: Played around with the MOVE procedure which allowed him to animate and vary the distance and timing. After a few-minutes of experimenting said "I like the old way better." Worked on elaborating his earlier animation procedure to allow the rocket to turn. Although he did this work on his own, he still seemed detached from the whole activity.

Session 16: class activity

Session 17: Most of the time was spent working on the articulation task.

Session 18: First part of period spent watching film. Ray then said that he wanted to draw a house. He drew one on paper, and together with teacher labelled the parts and wrote the procedure:

```
TO HOUSE
10 CENTER
20 SIDE
30 TOP
40 ROOF
END
```

Teacher expected that Ray would now write the necessary subprocedures. But Ray had supposed that the computer would know how to do these already and was unwilling to continue on the project. Then played some more with repeated designs and teacher introduced ***simple recursion*** as a way of getting things to repeat.

Sessions 19-20: Teacher introduced POLY and Ray experimented with different inputs. His choice of inputs seemed dictated by number patterns rather than by the effects on the drawings.

Session 21: Teacher introduced SPIRAL and Ray experimented with it. this time he began to focus on the drawings, rather than the number patterns.

Session 22: Ray came in with a definite idea of what to do -- combine POLY and SPIRAL and made designs which combined the two, experimenting with different inputs.

Session 23: Teacher supplied an LPOLY procedure which makes left-turning polys so that Ray could make symmetrical designs; but Ray didn't find these very interesting. Did more exploring with spirals, keeping the side and angle the same and varying the rate of growth.

Session 24: This was the first time Ray typed in things copied from his notebook without asking. repeated some of the spiral designs he had previously found interesting. Also made a snap on his own so that his rocket animation would work.

Session 25: Ray brought a visitor, and showed his procedures. This time he seemed to like making symmetrical shapes with POLY and LPOLY.

CLASS II

Sessions 1-4: All students in the class (Kathy, Monica, Donald, Kevin) worked closely together during sessions 1-4. These began by experimenting with the basic turtle commands. During session 2 the teacher showed how to define a ***procedure*** to draw a square and then suggested a project which used the square as a ***subprocedure***. Then the students suggested three more projects which used the square as a subprocedure. Sessions 3 and 4 were spent on planning and ***debugging*** the third of these projects (a pyramid consisting of 10 squares). Teacher introduced ideas of ***superprocedure*** and ***setups*** for the subprocedures. On all of this, the class worked together as a whole, and at one point even rejected teacher's suggestion that they split up to plan separate projects.

CLASS II: STUD[illegible] Kathy

Session 5: Kathy's first chance to work alone. Teacher suggested problem of drawing a triangle, and Kathy solved this quickly and defined a triangle procedure. Then, on her own defined

```
TO BUTTERFLY
1 TRIANGLE
2 TRIANGLE
END
```

Teacher suggested repeating BUTTERFLY and she defined a procedure which she called 7BUTTERFLY which repeated BUTTERFLY 6 times.

Session 6: Kathy and Monica worked together. They combined TRIANGLE and SQUARE to draw a house. Then Kathy suggested repeating the house. This made a symmetrical design. Kathy then created another design by superimposing the repeated house with her 7BUTTERFLY procedure.

Session 7: Kathy came in late, so it was a short period for her. She asked the teacher if the computer could draw a circle and teacher played turtle with her to develop the idea of repeating RIGHT 20, FORWARD 20 over and over.

Session 8: Kathy started where she left off last time, repeating RT and FD until it made a circle and then began teaching these steps as a long procedure. At about 8th or 9th step declared that she didn't know how many times to repeat this to make a full circle, and teacher showed her the idea of the ***total turtle trip*** as a way of figuring this out. Eventually she made a procedure, SHELL, which repeated the sequence 20 times (rather than 18) even though she knew it "would probably go too far." Teacher showed her the idea of repeating by ***simple recursion*** and she defined several procedures in this pattern, for example

```
TO TB
1 TRIANGLE
2 BOX
3 TB
END
```

Session 9: absent

Sessions 10-11: These were spent on more repeated designs, for example

```
TO SLINKY
1 SHELL
2 FORWARD 10
3 SLINKY
END
```

which makes a circular "coil." Teacher also introduced POLY (Kathy's first exposure to ***inputs***. Session 11 was devoted to a joint lesson with Monica on ***debugging simple recursive procedures***, and also exploring designs made with ***arc*** and ***circle primitives***.

Session 12: class activity (see ??)

Session 13: Kathy defined her first procedure with ***inputs***, a variable sized square, and used this as a subprocedure in a design for a bus (her first ***planned drawing***). Had trouble figuring out how to place the wheels. Then turned to superimposing different sized squares:

```
SQ 10
SQ 20
. . .
```

which makes a "growing square" design.

Session 14: Came in with her design all written out as a procedure called WOW and taught it to the computer. Teacher showed her how to do this using ***recursion with changing inputs***

```
TO SUPERWOW :SIZE
1 SQ :SIZE
2 SUPERWOW :SIZE+10
END
```

She also experimented more with arc designs and made a worm. Also a christmas tree, which she turned into a symmetric design

```
TO STAR
1 XMASTREE
2 STAR
END
```

Session 15: absent

Session 16: Class lesson on recursion with ***stop rule***. During second part of period Kathy copied from Monica a procedure called HORSE which draws an abstract design.

Session 17: A short session. Kathy defined BARN which repeats HORSE four times. (Note choice of name here -- the original "horse" name was an arbitrary one chosen by Monica.)

Session 18: Class watched film on computer graphics.

Session 19: Designs using arcs. Made a procedure MONSTER which has subprocedures MO, NS, TER.

Sessions 20-21: Teacher suggested she write a procedure using angles as an input (also stop rules)

```
TO SPINWOW :ANGLE
10 WOW
20 RIGHT :ANGLE
30 IF HEADING=0 STOP
40 SPINWOW :ANGLE
END
```

Experimented with different inputs. Also made a design called BIRDMAN by direct commands.

Session 22: Taught BIRDMAN as a procedure, copying the steps from her notebook. Had to debug since she had made some mistakes last time writing the steps into her notebook, and several steps had been left out. This required redoing the whole procedure rather than just adding the missing lines, since her procedure had the lines numbered by 1's. When she rewrote the procedure, she still numbered the lines by 1's!

Session 23: Kathy brought in a visitor, shows her some of her designs and shows her how to write procedures. She teaches the visitor to number procedure lines by 10's.

CLASS II: STUDENT -- Monica

Sessions 1-4: See notes for whole class above.

Session 5: Monica's first time alone at the terminal. Followed teacher's suggeston that she try to make a triangle. She worked on this the whole period, experimenting with different strategies. Although she did not "succeed" at this, she came very close, and teacher was impressed with her ability to stick to this one problem for the entire session.

Session 6: Worked with Kathy. See above.

Session 7: Used Kathy's TRI procedure, but modified it so that it was ***state transparent***. Then made a design by repeating TRI, LT 90 over and over. This TRI procedure is the germ of a style of work that lasted throughout the 25 sessions. Kathy's triangle was not state-transparent and so repeating it made a symmetric design. Monica's was state-transparent, so repeating it with turns in between made a symmetric design. Throughout the period of the experiment, Kathy's design investigations would be modelled on repeating a previously defined procedure; while Monica's would be modelled on "procedure, turn, repeat."

Session 8: More repeating designs. Teacher showed her how to use a ***counter*** and a ***stop rule*** and she copied these into her notebook but did not use them. Teacher also showed her ***simple recursion*** as a way of repeating her designs, and she made some procedures using this method.

Session 9: More fan-like designs. After a while she made a regular pentagon, and the teacher introduced the POLY procedure (first use of ***inputs***). She experimented with this and made a chart of the results. One thing to note: Monica does not use ***edit***. when a procedure does not perform as expected, she just stops using it rather than trying to debug.

Session 10: Copied a procedure form one of the worksheets, but she made a mistake and wrote the title as DOODLE rather than DOODLES, so the procedure became

```
TO DOODLE
10 DOODLE
20 DOODLE
30 DOODLE
40 DOODLE
END
```

So the procedure didn't do anything. She also made a flower design using the ***circle primitives***.

Session 11: Teacher conducts joint lesson with Kathy and Monica on debugging recursive procedures (like DOODLE above). Rest of period spent working with circles.

Session 12: Class activity.

Sessions 13-14: Taught computer variable sized square (***procedure with input***) and use squares to make a bus.

Session 15: Part of period spent working on articulation task worked on more repeated designs, and made independent use of ***simple recursion***. Also came in after school with two friends and showed them how to make repeated designs. Each friend defined a procedure.

Session 16-17: More repeated designs using recursion. She also made a christmas tree design (cf. Kathy, Session 14) except that she called the procedure HAT. Also repeated HAT to make designs, both when she was halfway through defining HAT and when she had finished the procedure.

Sesson 18: Class watched film.

Session 19: Teacher models of procedures with ***angle inputs*** and ***stop rules*** and she spent most of the time adopting these to her designs, as in

```
TO SPINBUS :ANGLE
10 BUS
20 RIGHT :ANGLE
30 IF HEADING=0 STOP
40 SPINBUS :ANGLE
END
```

Most of the time was spent debugging the syntax and little time was left for experimenting.

Session 20: absent

Session 21: Experimented with her variable angle procedures. Also edited her HAT (christmas tree) procedure to make the bottom of it "look even."

Sesson 22: absent

Session 23: Monica had a visitor and together they made a repeating circle design using recursion.

CLASS II: STUDENT -- Kevin

Sessions 1-4: See notes for entire class above.

Session 5: Following teacher's suggestion, to make a triangle, Kevin made a right isoceles triangle by trial and error (and used his trials to *edit* his evolving triangle procedure, which he called OF). Four repeated OF's made a flower, to which he added the stem. throughout this work he demonstrated clear understanding of 45, 90 and 180 degree angles. Also readily combines numbers on his own e.g., LT 45, LT 90 will become LT 135 on a second attempt at drawing the design. His flower procedure, which he did on his own, shows his ability to independently define procedures with ***subprocedures***.

Session 6: Following teacher's suggestion, he makes a house, combining his triangle, with the earlier defined square procedure. Then he defines 2HOUSE which uses the house procedure twice, moving the turtle in between to set up for the second house (attention to turtle ***state***).

Session 7: Kevin's first ***independently suggested project*** -- drawing a flag. He worked on the design using the square as a subprocedure, but later changed his mind and developed another flag using the BIGBOX procedure which the class had done on day 2. By the end of the period he'd completed the flag using BIGBOX together with direct commands, but had not taught it to the computer as a procedure. All through this work he showed an impressive ability to keep track of the turtle state, and to combine inputs of successive forwards and turns.

Session 8: absent

Session 9: Worked on teaching his flag as a procedure. Teacher showed him the idea of breaking it into subprocedures, but Kevin preferred to copy the long sequence of steps from his notebook. Most of the period spent debugging.

Session 10: Kevin decided not to finish his flag, and started on a new project -- a turtle. This was his first use of ***arcs***. Also, because he'd had so much trouble with the flag, he accepted the teacher's suggesion to use ***functional subprocedures***, and by the end of the period had completed the shell.

Session 11: Continued on turtle. Defined the subprocedure to draw the head.

Session 12: Class activity.

Session 13-15: More work on turtle, adding feet. Then he was interested in having it move, so talked through animation procedures with teacher.

Session 16: Class lesson on stop rules.

Session 17: Worked on animation and got turtle to move.

Session 18: Class watched film on computer graphics.

Session 19: Kevin's first real experimenting with ***inputs***: used POLY and POOLY (a two variable procedure), both procedures using ***simple recursion*** and ***stop rules***. He decided to use one of the poly's for the turtle's eye, but eventually gave up on this plan.

Session 20: Teacher introduced him to ***recursion with changing inputs*** and talked through:

```
TO TUNNEL :SIZE
10 POLY :SIZE 45
20 IF :SIZE=105 STOP
30 TUNNEL :SIZE+5
END
```

Session 21: A real leap in understanding today. Kevin defined independently several procedures on the model of TUNNEL. Also added variables to change the rate at which the figures grew (teacher's suggestion) and the size of the largest figure (Kevin's suggestion). Clear demonstration of understanding the concept of variable.

Session 23: No computer work. Kevin spent the time drawing star wars pictures.

Session 24: Brought in a friend and taught him how to write procedures. Kevin illustrated for his friend the theory of procedures by defining

```
TO ACE
10 POLY 90 45
END
```

CLASS II: STUDENT -- David

Sessions 1-5: See notes for whole class above. David initiated the ideas for BIGBOX and PYRAMID. He was absent for Sessions 4 and 5.

Sessions 6-7: Followed teacher's suggestion to work on and debug house picture.

Session 8: Worked a long time with direct commands, and drew a city. Teacher suggested he teach this to the computer and he defined a ***subprocedure*** called LITTLE which would draw the outline of a building. Then switched to experimenting with square and triangle. At end of class was working on drawing a face.

Session 9: Teacher showed him how to make a variable sized square. (First use of ***inputs***.) Used this as part of face.

Sessions 10-11: Readily adopts style of ***top-down planning*** and ***functional subprocedures***. Defines subprocedures HEAD, EYES, NOSE and works on positioning an ***arc*** for the mouth.

Session 12: class activity

Sessions 13-14: Finished mouth and added beard. Spent a long time working at positioning the beard. Beard is formed by REPEATing a subprocedure which draws a strand and turns a little.

Session 15: Teacher gave David a lesson in the geometry of arcs, which helped him very much in his efforts on positioning the beard. With this he was able to straightforwardly finish the beard and add hair and ears.

Session 16: lesson on stop rules.

Session 17: Added hat to face, and spent time working on positioning the hat. He had three variables to coordinate in this task -- size of hat, size of brim, and starting position.

Session 18: Class watched movie on computer graphics.

Session 19: David wanted to use POLY to add a flower to the hat. Teacher showed him how to write ***recursive*** POLY with ***stop rule***. David used this to make a flower. His face procedure is a model of top-down planning:

```
TO FACE
1 BOX
2 EYES
3 NOSE
4 MOUTH
5 BEARD
6 HAIR
70 EARS
80 HAT
85 FLOWER
END
```

Session 21: Worked for the whole period locating the stem for the flower. For this he used an ***arc*** procedure and systematically varied both the arc radius and the starting location.

Session 22: David ran in to an interesting bug -- the POLY flower at the end of the arc doesn't start out with the turtle straight up, so the stop rule (IF HEADING=0 STOP) doesn't work. Teacher explains that he should turn the turtle before starting the POLY. David seems to understand this bug, and the solution. The face is now finished. All in all David has spent 12 sessions over a period of 4 weeks on this single project!

Session 23: Brings his older sister (grade 8) to visit and helps her draw her initials by direct commands.

Session 24: Retaught FLOWER (which was lost) to the computer. He did not have his written notes, but did remember most of the steps. But he did not remember the turn that the teacher had suggested to fix the stop rule bug, and had to be reminded how to fix the bug.

In this part of the report we summarize and compare the students' acquisition of Logo programming skills along a number of dimensions. For each of the elements of Logo programming listed below we give the session number of the student's first contact with this concept, the numbers of the sessions in which the concept was used with help, and the initial sessions in which the concept was used independently with confidence.

basic turtle commands

arc and circle primitives

PRINT and TYPE commands

defining procedures

subprocedures

procedures with inputs

conditionals and stop rules

simple recursion

recursion with varying inputs

basic turtle commands

	1st contact	uses with help	uses independently
Gary	1	2	1,2,6
Deborah	2	3,4	6,8,9
Ray	2	3,4	8,9
Laura	1	1,2	5,6
Kathy	1	2,4	5,6
Monica	1	2	4,5,6
Kevin	1	2	3,4,7
David	1	2	3,6,7

arc and circle primitives

2	1st contact	uses with help	uses independently
Gary	5		5,14,15
Deborah	4	9	14
Ray	8		
Laura	5	7	6,9,10
Kathy	10	11	13,19
Monica	9	11	13,19
Kevin	10	10	11,13
David	10	10	

PRINT and TYPE

	1st contact	uses with help	uses independently
Gary	3	5	22
Deborah			
Ray			
Laura	4,5	16,17	
Kathy	15		
Monica	15		
Kevin	15		
David	15		

defining procedures

	1st contact	uses with help	uses independently
Gary	1	2	3
Deborah	3	5,7,8	10,14
Ray	3	4,8,9,10,13	
Laura	1	7,8	9,10
Kathy	2	3	5,6
Monica	2	3	4,6
Kevin	2	3	4,5,6
David	2	3	6,7

subprocedures

	1st contact	uses with help	uses independently
Gary	1	2	5,7,8
Deborah	5	18,19	22,23
Ray	9	10,13	
Laura	1	7,8,10,11,16	
Kathy	2,3	4,5	6,8
Monica	2,3	4,5	6,8
Kevin	2,3	4	5,6
David	2,3	7	10,13

Procedures with inputs

	1st contact	uses with help	uses independently
Gary	9	14,15,22	23,24
Deborah			
Ray	18,20		
Laura	12	13,14,21	
Kathy	10	13,15,20	
Monica	9	13,18	21
Kevin	15	19,20	21
David	9,15	19	

conditionals and stop rules

	1st contact	uses with help	uses independently
Gary	10	11,22	22
Deborah	15		
Ray	18,23		
Laura	17	21,22	
Kathy	12,15	20	
Monica	8,12	19	
Kevin	12,15	19,20	21
David	15	19	

simple recursion

	1st contact	uses with help	uses independently
Gary	4	9	10,11
Deborah	15		
Ray	15		
Laura	12	18	21
Kathy	7	8,10	13,20
Monica	8	8,9,10	14,15
Kevin	14	19,20	21
David	15	19	

recursion with varying inputs

	1st contact	uses with help	uses independently
Gary	22	22	
Deborah			
Ray			
Laura	14,17		
Kathy	13,15	20	
Monica	15		
Kevin	15	20	21
David	15		

Appendix III - Checklist of LOGO Skills Used for Daily Observation

Name____________________

OBSERVATION CHECKLIST I -- Use of Keyboard

	Initial Contact	Uses with Help	Uses Independently with Comfort
LOGIN			
Carriage Return			
DELETE			
CONTROL-G			
Shift key as needed			
Space Bar			
CONTROL keys for editing			
CTL-N			
CTL-C			
CTL-R			
CTRL-S			
CTL-W			

Name______________________

OBSERVATION CHECKLIST II -- Turtle Commands

	Initial contact	Uses with Help	Uses Independently with Comfort
CLEARSCREEN or CS			
FORWARD or FD			
BACK or BK			
RIGHT or RT			
LEFT or LT			
PENUP or PU			
PENDOWN or PD			
SHOWTURTLE or ST			
HIDETURTLE or HT			
XCOR, YCOR			
HEADING			
HOME			
SETTURTLE or SETT			
SETX, SETY, SETXY			
SETHEADING			
HERE			
RCIRCLE			
LCIRCLE			
RARC			
LARC			

Name______________

OBSERVATION CHECKLIST III -- Editing, Naming and Printing Commands

	Initial Contact	Uses with Help	Uses Independently with Comfort
TO			
END			
LINE NUMBERS			
EDIT or ED			
PRINTOUT or PO			
PRINTOUT TITLE or POTS			
ERASE or ER			
ERASELINE or ERL			
EDIT LINE or EDL			
EDIT TITLE or EDT			
WRITE			
READ			
: in a procedure title			
MAKE			
: and "			
PRINT with " and [ ]			
PRINT with operations			
TYPE with " and [ ]			
TYPE with operations			
REQUEST			
TYPEIN			
SENTENCE			
WORD			

Name____________________

OBSERVATION CHECKLIST IV -- Control Commands and Miscellaneous Commands

	Initial Contact	Uses with Help	Uses Independently with Comfort
GO			
RECURSION			
IF			
TEST, IFTRUE, IFFALSE			
STOP			
OUTPUT			
List Processing: FIRST or F			
BUTFIRST or BF			
LAST or L			
BUTLAST or BL			
Arithmetic Operations: +, -, *, /, \,			
RANDOM			
Animation: SNAP			
DISPLAY			
WIPECLEAN or WC			
WIPE			
Others: WRAP			
SPIN			
MOVE			

Name____________________

OBSERVATION CHECKLIST V -- LOGO Programming Ideas

	Initial Contact	Uses with Help	Uses Independently with Comfort
Sequential Procedure			
Subprocedures			
Simple Recursion			
Procedures with Inputs			
Procedures with Conditionals			
Procedures with Stop rules			
Procedures with Counters			
Recursion with Varying Inputs			
Iteration and Looping			
Procedures with Outputs			
Complicated Recursion (mixed-up inputs)			

Name____________________

OBSERVATION CHECKLIST VI -- Planning, Debugging and Problem Solving

	Initial Contact	Uses with Help	Uses Independently with Comfort
Planning or Drawing on Paper			
Playing Turtle			
Playing Computer			
People Procedures			
Reads error message and corrects errors			
Uses line number in error message for debugging			
Uses Superprocedures and top-down planning			
Uses an old procedure in a new way			
Bug Types:			
Turtle State			
Typing			
Out of Bounds			
Program Control			
Naming			
Syntax (: & " etc.)			

Name________________________

OBSERVATION CHECKLIST VII -- Mathematical Skills and Concepts
A. Turtle Geometry

	Initial Contact	Uses with Help	Uses Independently with Comfort
Recognizes Size of Screen			
Estimating Length			
Estimating Angles			
Special Angles:			
90			
180, 360			
120			
60			
45			
Shapes			
Square			
Triangle			
Hexagon			
Other Polygons			
Stars			
Rectangles			
Spirals			
Circles			
Radius of Circle			
Diameter of "			
Similarity and Scaling			
Symmetry: Right/Left Reversability			
Back/Forward			
Symmetrical Shapes			
Axes of Symmetry			
Effects of Rotation			
Total Turtle Trip			
Rate of Curvature			
Cartesian Coordinates			

Name____________________

OBSERVATION CHECKLIST VIII -- Mathematical Skills and Concepts
B. Non-Turtle Geometry

	Initial Contact	Uses with Help	Uses Independently with Comfort
Variables to Control Size and Direction			
Variables to Control Procedures			
Positive and Negative Numbers			
Use of Conditionals			
Decimal Numbers			
Logic in Program Control			
Finding Patterns			
Procedural or Algorythmic thinking			

Name__________________________

OBSERVATION CHECKLIST IX -- Language Activities

	Initial Contact	Uses with Help	Uses Independently with Comfort
Attention to "spelling"			
Reads and Interprets Error Messages			
Conversational Procedures			
Quiz or Question-asking procedures			
Sentence Generators			
Poem Generators			

Name________________

OBSERVATION CHECKLIST X -- Working Style, Interpersonal Relationships and Communication

Attempts to solve problems on his own ____________________

Asks for Help: regularly sometimes seldom

Gives Up easily ____________________

Jumps from one activity to another ____________________

Is self motivated ____________________

Seeks guidance from teacher ____________________

Seeks guidance from classmates ____________________

Shifts purpose flexibly when a new idea emerges ____________________

Initiates ideas for projects ____________________

Follows through on ideas ____________________

Shows work to a classmate ____________________

Shows interest in classmates' work ____________________

Helps a classmate ____________________

Ask for help from classmate ____________________

Borrows an idea from classmate ____________________

Collaborates with Classmate ____________________

COMMUNCATION:

Talks articulately with classmates about work ____________________

Talks articulately with teacher about work ____________________

Talks about problem-solving strategies ____________________

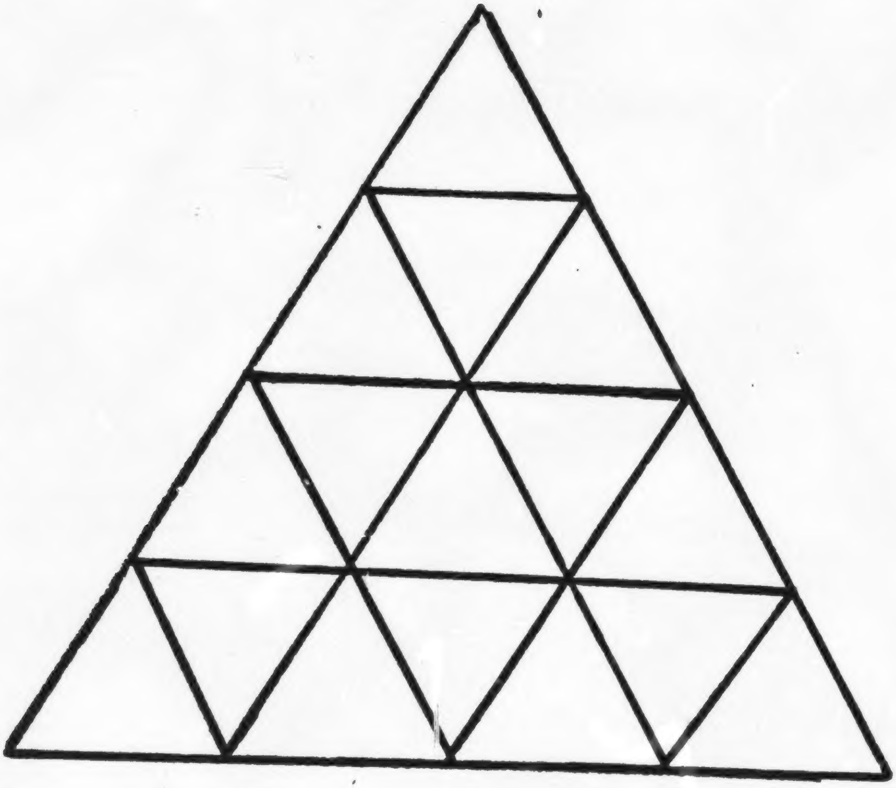
Uses "computer terminology" in talking about LOGO work ____________________

Uses "computer terminology" in talking about non-computer activities ____________________

Appendix IV - Excerpts from the Pre/Post Interview Schedule

Interview Schedule

How many triangles do you find in this design?



See which of these number patterns you can complete.

a) 1, 3, 5, 7, ___, ___, ___

b) 126, 127, 128, ___, ___, ___,

c) 134, 133, 132, ___, ___, ___,

d) 1096, 1097, 1098, ___, ___, ___

e) 1, 2, 4, 8, ___, ___, ___

f) 12, 15, 18, 21, ___, ___, ___

g) 1, 4, 9, 16, ___, ___, ___

h) 1, 12, 23, 34, ___, ___, ___

i) 1, 1, 2, 3, 5, 8, ___, ___,

Grade these subject areas according to your preference.
A, B, C, D, F

Mathematics

Music

Reading

Art.

Writing Stories

Phys Ed/Gym

Spelling

Shop

Science

Home Economics

Social Studies

Recess

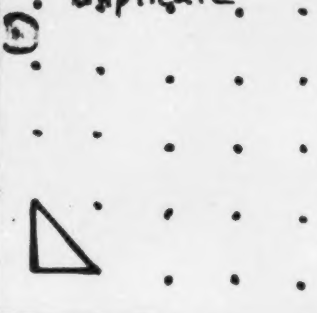
Handwriting

Are there any areas that have been left out?

Interview

Student Attempts

duplicate



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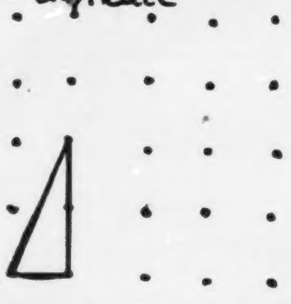

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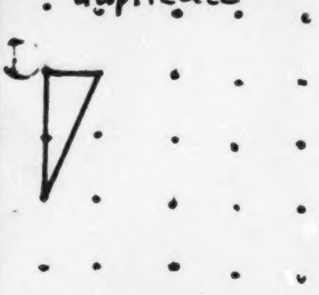

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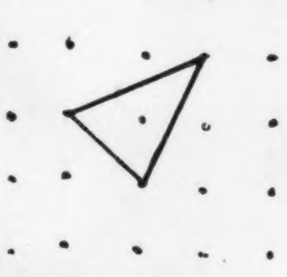

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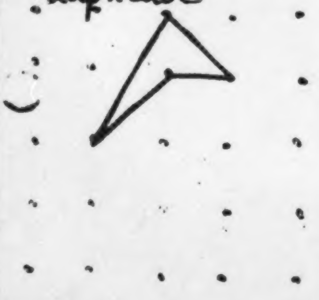
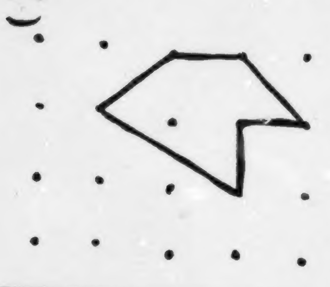


Student :
Date :

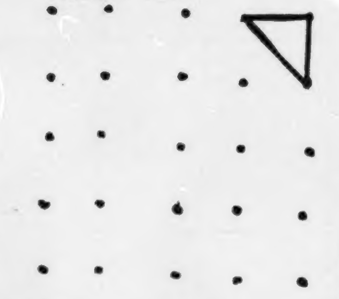
Interviewer

Student Attempts

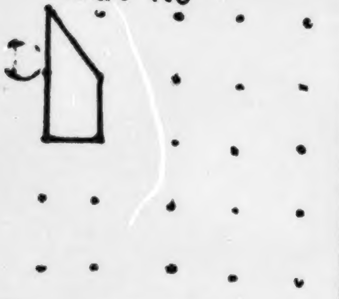
duplicate



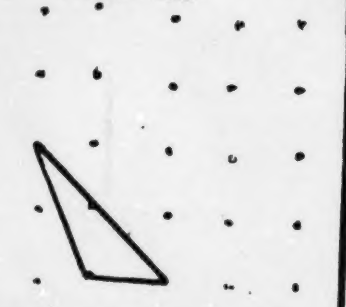
rotate 180°



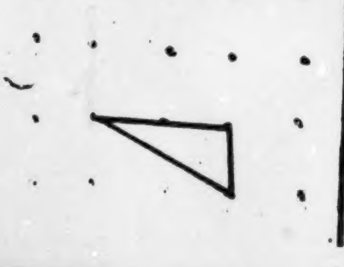
rotate 180°



rotate 180°



rotate 180°

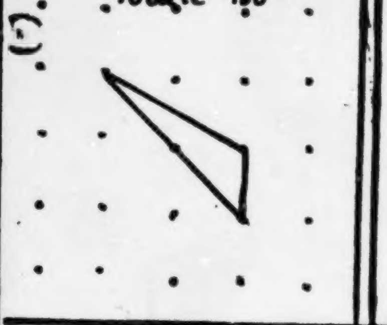


Student:
Date:

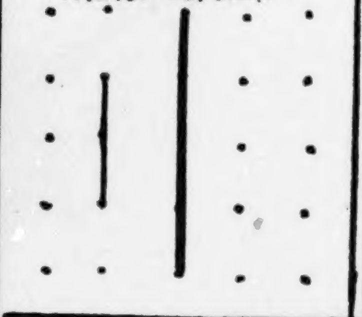
Interviewer

Student Attempts

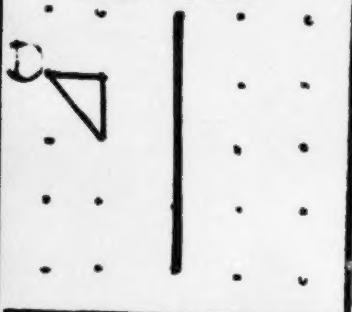
rotate 180°



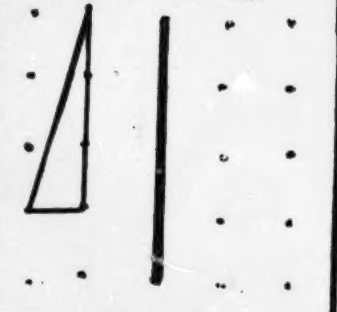
mirror vertical



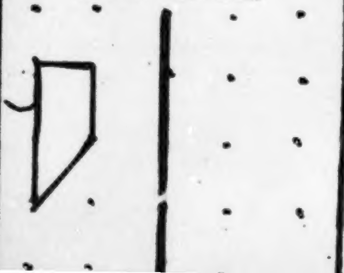
mirror vertical



mirror vertical



mirror vertical



Date:

Interviewer

Student Attempts